FINAL REPORT

INSTRUMENTATION FOR MEASURING IRRADIANCE IN THE UV-B REGION

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Washington, D.C. 20460

Annual Report 1977

EPA Interagency Program on Biological and Climatic Effects (BACER)
Instrumentation for Measuring Irradiance in the UV-B Region

SUMMARY

The responsibility of the Instrumentation Research Laboratory (IRL) in this program was developing portable instruments for use by biologists to measure UV-B irradiance in growth chambers, greenhouses, and field plots. A simple UV-B radiometer and two UV-B spectroradiometers have been designed, constructed, tested, and put into use in the UV-B research program. Each of these instruments is now being manufactured by commercial firms.

The two spectroradiometers differ only in the monochromators: one has a single holographic grating; the other, two holographic gratings for greater stray light rejection. The spectroradiometers automatically scan the 250-400 nm region in less than 5 minutes, printing a tape of the corrected irradiance as a function of wavelength. The input is cosine corrected by a specially designed teflon-bubble diffuser coupled to the input slits. The output of the monochromator is measured with a multiplier-type phototube and a logarithmic response amplifier. The amplifier output is digitized with a digital voltmeter, and the digital output is interfaced with a desk-top programmable calculator.

The design provided for the spectroradiometer system response to be stored in the calculator so that, as the spectrum is scanned, the calculator corrects the measured signal for instrument calibration and outputs the true spectral irradiance of the source being measured.

The programmable calculator controls the operation of the spectroradiometer so that, on command, scanning is initiated and readings are recorded for each nanometer interval. The calculator prints the wavelength and irradiance for each wavelength interval and, at the end of the scan, reverses the wavelength drive and returns the monochromator to the starting wavelength. The calculator is programmed to print an integral for a programmed action spectrum at the end of each scan. At the completion of the scan, the data can be stored on a magnetic tape, if desired, for future analyses.

Provision is included for a precise check of wavelength: the spectrum of a miniature low-pressure mercury-arc lamp is scanned, and the calculator computes the position of the 253.7 nm and the 296.7 nm lines to a precision of $\pm$ 0.01 nm.

The performance specifications approach the requirements for UV-B measurements stated in NBS publication #20, "Optical Radiation News," dated April 1977.

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Our UV-B measuring instruments developed for this project meet the requested requirements. The broadband radiometer is small, hand-held, battery operated, and has fast response for rapid measurements. The spectroradiometers have the following features:

(1) Fast, accurate, and reproducible.

(2) Convenient, automatic single-key-stroke operation.

(3) Programmable calculator-controlled scanning, Fig. 1.

(4) Logarithmic amplifier for wide dynamic range.

(5) Calculates and prints true spectral irradiance for each nm wavelength, Fig. 2.

(6) Calculates and prints weighting function (AΣ9).

(7) Programmed-wavelength-calibration check.

(8) Double monochromator unit has very low stray light.

(9) Bandwidth of 2 nm.

(10) Temperature stable.

(11) Receptor has excellent cosine response.

(12) Spectra are stored on magnetic tape for efficient data processing.

(13) Portable--operates on small lab cart.

(14) Minor disturbance of area by the "measuring head."

Our spectroradiometer performance specifications approach the requirements for UV-B measurements stated in NBS publication #20, "Optical Radiation News," dated April 1977. These requirements are cited in attached copy of "Making a UV Measurement?," Electro-Optical Systems Design, 9(6):17, 1977. (page 7)

Cosine Response for UV-B

The spectroradiometers, as well as other UV-B radiation meters developed in our program, incorporate a new design for cosine-corrected input optics. We tested all available cosine-correction schemes, including integrating spheres, diffusing reflectors, and sintered-quartz diffusers. None of these gave adequate performance for the 250 to 370 nm region, so we developed the

teflon bubble diffuser. The spectral transmission of this teflon diffuser is shown in Fig. 3. Fig. 4 is a drawing of the input optics for the spectroradiometers. We supplied a similar receptor to our cooperators that have a Gamma Scientific monochromator, Fig. 5. The response of this type of diffuser to radiation from different angles is compared with that of a commercial instrument in Fig. 6. The teflon bubble receptor provides excellent cosine correction, and has a stable surface which can be readily cleaned. This type of diffuser is now used in commercial instruments.

Wavelength Accuracy

To check spectroradiometer wavelength accuracy, a low-pressure mercury-arc lamp is scanned and the mercury line location computed. The wavelengths of the 253.7 and the 296.7 nm lines are measured with a readout precision of ± 0.01 nm, so that wavelength shifts as low as 0.02 nm are readily detected, Fig. 7. This field check can be made quickly and routinely between measurements if desired.

Spectroradiometers

Our UV-B spectroradiometers are now used routinely by technicians to measure UV-B irradiance in growth chambers, greenhouses, and field plots. These instruments are identified by the acronyms: IRLSpec-S for the single monochromator version; IRLSpec-D for the double monochromator; and IRLSpec-SO for the commercial model single monochromator. Numbers shown on the graphs--for example, 1770815.09--identify instrument (first digit), year (next two digits), month, day, and scan number for that day. The first digit may be 1, 2, or 3 for IRLSpec-S, IRLSpec-D, or IRLSpec-SO, respectively.

Measured performance specifications for the IRLSpec-S spectroradiometer are as follows:

Wavelength range - 250 to 370 nm
Readout interval - 1 nm
Scanning speed - 0.5 nm/sec.
Spectral bandpass - 2 nm
Wavelength reproducibility - ± 0.02 nm
Wavelength accuracy - ± 0.05 nm at 296.7 nm
Radiometric reproducibility - ± 2%
Radiometric accuracy - ± 5%
Radiometric range - 0.001 to 2000 $mW \cdot m^{-2} \cdot nm^{-1}$
Stray light - less than 2 x 10^{-4} at 285 nm as tested with a xenon arc lamp filtered with 0.5-mm-thick cellulose acetate
Cosine correction - within ± 10%
Output - printed tape direct reading in wavelength and corrected irradiance at each nanometer interval from 250 to 370 nm
Size of measuring head - less than 28 x 20 x 10 cm
Temperature stability less than 0.04 nm wavelength shift for 25°C temperature change.

The IRLSpec-D spectroradiometer, with double-grating monochromator, provides better stray light rejection. This unit incorporates all the features of the single monochromator unit although the measuring head is, of necessity, slightly larger. Observed wavelength instability of the double monochromator was caused by grating-sync-drive cable temperature sensitivity. Our technician, George Button, solved this temperature instability with his cable-stringing technique. The grating-drive cable spring was eliminated, and the cables were crossed to provide automatic temperature compensation and wavelength stability.

Measured performance specifications for the IRLSpec-D spectroradiometer are as follows:

Wavelength range - 250 to 370 nm
Readout interval - 1 nm
Scanning speed - 0.7 nm/sec.
Spectral bandpass - 2 nm
Wavelength reproducibility - $\pm$ 0.02 nm
Wavelength accuracy - $\pm$ 0.05 nm at 296.7 nm
Radiometric reproducibility - $\pm$ 2%
Radiometric accuracy - $\pm$ 5%
Radiometric range 0.0001 to 1000 $mW \cdot m^{-2} \cdot nm^{-1}$
Stray light - less than 5 x 10^{-8} at 285 nm as tested with a xenon arc lamp filtered with 0.5-mm-thick cellulose acetate
Cosine correction - within $\pm$ 10%
Output - printed tape direct reading in wavelength and corrected irradiance at each nanometer interval from 250 to 370 nm
Size of measuring head - less than 28 x 25 x 10 cm
Temperature stability - less than 0.06 nm shift for 25°C temperature change.

The IRLSpec-D spectroradiometer was field tested at the University of Colorado's Snowmass, Colorado, high-altitude site during August. The instrument was disassembled into components and securely packed into a regular hard-side luggage as a shipping container and transported as "checked" baggage to and from Colorado. Spectral measurements were made at three elevations, 2377 m (7800 ft.), 2980 m (9777 ft.), and 3452 m (11326 ft.). This necessitated disassembling and repacking the instrument and transporting it up and down the mountain on unimproved roads to each site. Upon return to Beltsville, the instrument continued to perform with only minor adjustments.

The commercial version of our IRLSpec-S, single monochromator spectroradiometer was manufactured to our specifications. This IRLSpec-SO required constant operator assistance, but our circuit modifications converted it to automatic operation with single-key stroke to scan the spectrum, return, and reset.

Measured performance specifications for this commercial IRLSpec-SO spectroradiometer are as follows:

Wavelength range - 250 to 370 nm
Readout interval - 1 nm
Scanning speed - 1.0 nm/sec.
Spectral bandpass - 2 nm
Wavelength reproducibility - $\pm$ 0.02 nm
Wavelength accuracy - $\pm$ 0.05 nm at 296.7 nm
Radiometric reproducibility - $\pm$ 2%
Radiometric accuracy - $\pm$ 5%
Radiometric range - 0.001 to 200 $mW \cdot m^{-2} \cdot nm^{-1}$
Stray light - less than 1×10^{-4} at 285 nm as tested with a xenon arc lamp filtered with 0.5-mm-thick cellulose acetate
Cosine correction - within $\pm$ 10%
Output - printed tape direct reading in wavelength and corrected irradiance at each nanometer interval from 250 to 370 nm
Size of measuring head - less than 25 x 21 x 13 cm
Temperature stability - less than 0.04 nm shift for 25°C temperature change.

Spectroradiometer Sensitivity and Dark Current

The photomultiplier-tube dark current, system correction, and standard-lamp spectral irradiance are plotted in Fig. 8 for the IRLSpec-S with Hamamatsu R166 phototube (solar blind response) and Corion SF-1.25 solar blind filter. The IRLSpec-D photomultiplier dark current (Hamamatsu R212, S-5 response and Corion SF-1.25 solar blind filter), system correction, and standard lamp spectral irradiance are plotted in Fig. 9. Plots of the IRLSpec-SO photomultiplier-tube dark current (Hamamatsu R166, solar blind response, and Corning 7-54 filter), system correction, and standard lamp spectral irradiance are shown in Fig. 10.

The instruments developed in our program are now manufactured. A broad-band UV-B radiometer is available from Optronic Labs, Inc. Spectroradiometers similar to ours are advertised in Optical Spectra, 12(1):13,51, and 60, dated January 1978, and are available from three firms:

EG&G, Inc.
35 Congress Street
Salem, Massachusetts 01970

Gamma Scientific, Inc.
3777 Ruffin Road
San Diego, California 92123

Optronic Labs, Inc.
7676 Fenton Street
Silver Spring, Maryland 20910

Irradiance Spectra

Typical spectra from our IRLSpec-D are plotted in Fig. 11, 12, 13, and 14; from our IRLSpec-S, Fig. 15 and 16; and from our IRLSpec-SO, Fig. 17.

Irradiances of FS40 and FBZS40 lamps are compared in Fig. 11. A typical curve for an FS40 lamp with and without a cellulose acetate (CA) filter is shown in Fig. 12. CA filters with FS40 lamps are compared in Fig. 13. Measured irradiances of four FS40 lamps used to enhance the sun's UV-B at Snowmass, Colorado's 2980 m (9777 ft.) site, are plotted in Fig. 14. The fixtures were two lamps mounted in pairs at a Z of 110 cm and filtered with 0.127-mm (0.005-in.) CA. The change in irradiance of a FBZS20 lamp after aging 16.5 hr. is shown in Fig. 15. The irradiance measurements of two Sylvania F15T8 CW lamps at Z = 8 cm are compared for the IRLSpec-S, Fig. 16; the commercial IRLSpec-SO, Fig. 17; and the IRLSpec-D, Fig. 18. Irradiance for a 15-watt daylight lamp is shown in Fig. 19.

Spectral data of the sun at Beltsville, Maryland, during the year are plotted in Fig. 20 and 21. The sun curve on a very clear day illustrates the stray light at wavelengths below 289 nm for the IRLSpec-D, Fig. 22. The action spectra of measured Beltsville sunshine with weighting function 9 are shown in the region of 294 to 318 nm at the bottom of Fig. 20.

The weighting function plotted on the graphs is the AΣ9 equation developed in cooperative research at BARC:

$$\hat{y} = \left[0.25(\lambda/228.178)^{9.0}\right]^{4} \exp\left[4-(\lambda/228.178)^{9.0}\right]$$

The equation was used to compute UV-B sun equivalent (UVSEB), indicated on the graphs. Details of its development are presented in the Agricultural Equipment Laboratory report.

Spectral irradiance data are now plotted automatically with the HP9815A calculator interfaced directly and controlling a HP9872A plotter. After the data are recorded on the cassette, selected scans are loaded into the calculator; and the plotter draws and labels the graph to programmed dimensions, and then automatically plots the data (Fig. 11, 12, 13, and 14). A curve is plotted from 250 nm to 370 nm in 25 seconds.

Narrow-band Radiometers

Two narrow-band, probe-type radiometers were commercially manufactured to our specifications. These radiometers have solar-blind photo-multiplier-type detectors (Mfg. No. R166), a peak response at 294 nm and 299 nm, respectively, and a half-band width of 5 nm. Irradiance readout is a 3 1/2 digit display located in the remote electronic unit with switched ranges from 10^{-4} to 10^{-11} $watt \cdot cm^{-2} \cdot nm^{-1}$. The small sensor head (5x5x16 cm), with teflon dome receptor, is attached by 2.75-m cable for easy placement within growth chambers.

Broad-band UV-B Radiometers for Routine Monitoring

A small battery-powered radiometer, the IRLMeter, was designed and constructed for measurement of total UV-B radiation from artifical sources. The instrument has a solar-blind vacuum photo-diode (Hamamatsu R403), an integrated circuit amplifier, and a microammeter packaged in a meter case. The circuit, as shown in Fig. 23, provides for four decades of range switching. The relative wavelength response, as shown in Fig. 24, peaks at 300 nm and is relatively flat from 280 to 320 nm and the radiometer is not sensitive to radiation longer than 400 nm. Typical comparative data of the IRLMeter with the IRLSpec-S spectroradiometer are shown in Fig. 25.

This broad-band UV-B radiometer sensitivity is adjusted to a full scale reading of 2.0 UV-B sun equivalents, Beltsville (UVSEB) when measuring the output of FS40 fluorescent lamps filtered with 0.127-mm (0.005 in.) CA. Correction factors were developed for use with FS40 lamps with 0.254-mm (0.010 in.) CA filter, and for use with BZS fluorescent lamps.

The IRLSun-meter radiometer is a modification of the IRLMeter. The new calibration reads directly in sun equivalents, Beltsville (UVSEB AΣ9). Calibrations for two suns (UVSEB AΣ9) full scale were developed for four sources:

(1) Sunshine for a clear day (6/8/77), 1:00 p.m. EDT

(2) FS40 lamps filtered with 0.127-mm (0.005 in.) CA

(3) FS40 lamps filtered with 0.254-mm (0.010 in.) CA

(4) FBZS40 CLG lamps (unfiltered)

A commercial version of the IRLMeter has been manufactured, the Optronic Model 725. These Model 725 radiometers were calibrated by IRL for our cooperating laboratories from IRLSpec-D irradiance values for five sun equivalents full scale, with FS40 source filtered by 0.127-mm (0.005 in.) CA aged 6 hr. A calibration scale factor was developed for 0.191-mm (0.0075 in.) CA, 0.254-mm (0.010 in.) CA, 1.52-mm (0.036 in.) petri dish, and FBZS40 and FBZS20 lamps.

An Optronic Model 725 broad-band radiometer was calibrated from IRLSpec-D irradiance values for 10 UVSEB full scale with a Rayonet F8T5 RPR3000A (8 watt) lamp source filtered with 0.127-mm (0.005 in.) CA supplied by the Peoria cooperators and then aged 6 hr. This Peoria CA filter absorbed less at shorter wavelength than Beltsville CA, Fig. 26, 27, and 28, significantly changing the AΣ9 action integral.

Rayonet F8T5 RPR3000A (8 watt) lamps have strong energy in the 254 nm region, the energy approaching the peak value at 313 nm (ratio 1.4). The peak energy of the FS40 at 313 nm is approximately 700 times the energy at 254 nm. This 254 nm energy can be removed with CA filter, but it probably accelerates the aging of the CA filter. The irradiance of the Rayonet RPR3000A with the CA filter at 20 cm approximates the energy of the FS40 with CA filter at 50 cm and 75.1 cm, Fig. 29, 30, 31, and 32.

Eye Protectors

Personal eye protectors were evaluated for their UV-B attenuation, and two FS40 lamps at 50 cm from the IRLSpec-D spectroradiometer receptor were used. An aperture through black cloth was necessary to prevent significant leakage between lens and receptor, even though they were placed as close as possible. Plots of plastic goggles No. 6, 7, and 8 (dashed line) are at the 0.001 irradiance level in Fig. 33. No. 5 was a pair of plastic goggles, and No. 2, a plastic face shield. UV-B blocking of prescription eyeglasses (glass and plastic) and sunglasses are shown in Fig. 34.

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News

Making a UV Measurement?

Washington, D. C. — The increasing interest in ultraviolet optical measurements has spurred the National Bureau of Standards' Optical Radiation and Radiometric Physics groups to look into the matter. (A special chapter of the NBS Self-study Manual on Optical Radiation Measurements will be devoted to making state-of-the art accuracy UV measurements and is planned for later this year.) Over the past few months, NBS has investigated and characterized several currently available spectroradiometers suited for use in the UV, in a program sponsored by the EPA.

To summarize their findings (see *Optical Radiation News*, April 1977), the current state-of-the-art for spectral irradiance measurements in the 250-350 nm range varies widely. The uncertainty for a highly controlled laboratory measurement of radiation of a simple character is estimated at about 3%. At the other extreme, the measurement of very complex radiation under very unfavorable field conditions could hit 26%. Typical uncertainties for lab and field are estimated to be about 6% and 15%, respectively.

What can be done to improve these "best" UV measurements? NBS believes that what is needed most is a field-portable spectroradiometer with some impressive characteristics. This instrument would not only have negligible out-of-band leakage ($\approx 10^{-8}$) and high wavelength accuracy ($\approx$ 0.03 nm) but would also be much less sensitive to temperature and mechanical shock, be hermetically sealed and have an easily replaceable window on its entrance port. Difficult field measurements could be made to within 10% uncertainty with such an instrument. NBS also suggests microprocessor control for this device.

(Ed. note: The technology for such a device exists. But such a spectroradiometer would necessarily be a "big ticket" item even if we disregard the mechanics of just how the development expenses are amortized. There is some question of whether the potential market is big enough to be able to absorb the development costs.)☐

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LIST OF FIGURES

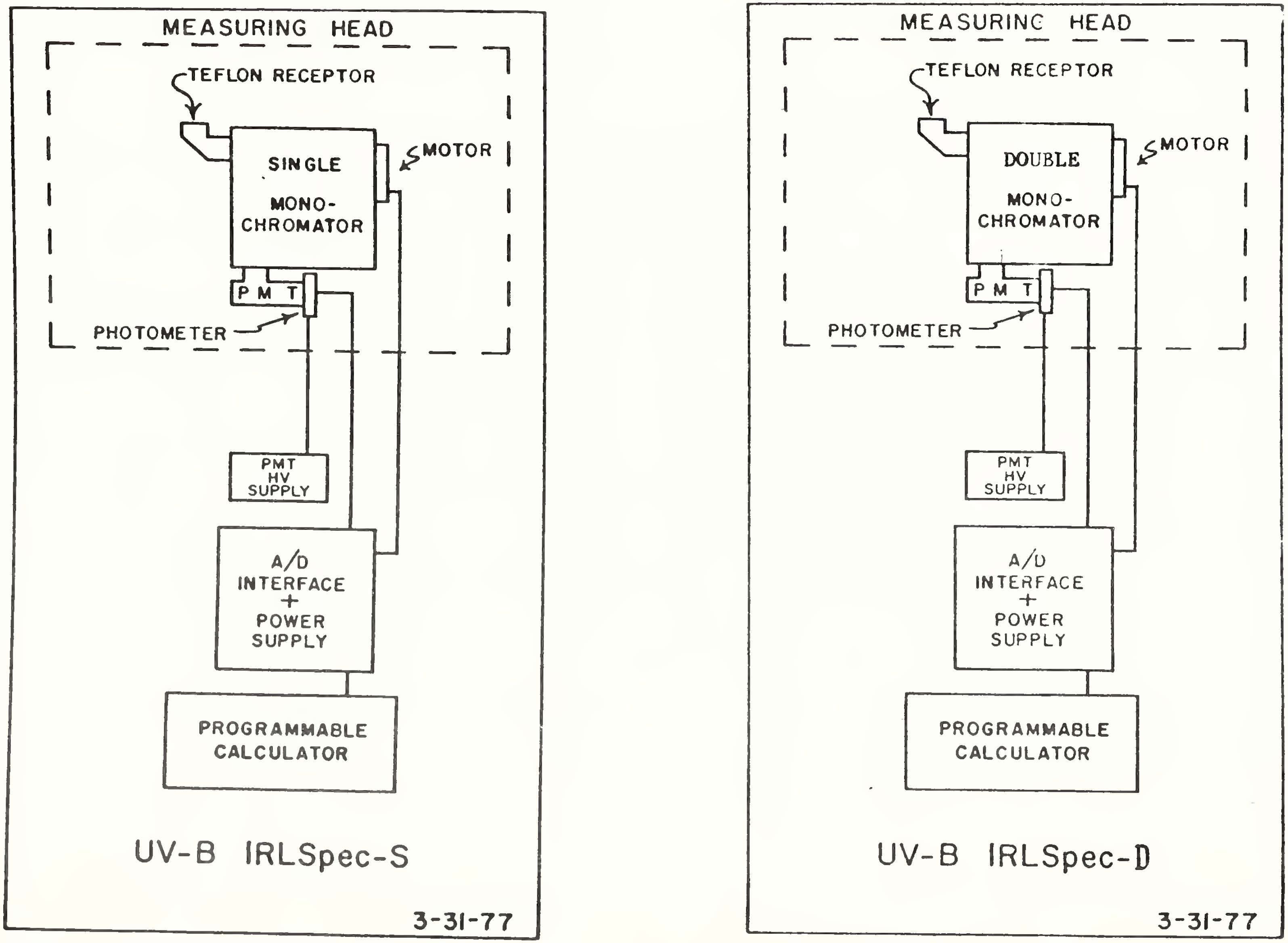

Fig. 1. Spectroradiometer components

```
FILE    -17 D3
TYPE     2
USED     1208
MAX      1208
F540 Z=50cm
 2780203.09
250000.0039
251000.0048
252000.0305
253000.1084
254000.2177
255000.1071
256000.0087
257000.0030
258000.0027
259000.0027
260000.0022
261000.0024
262000.0031
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264000.0095
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272000.2473
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275000.7620
276001.0823
277001.3153
278001.6617
279002.1661
280003.0536
281004.0457
282004.7257
283005.6125
284006.8764
285008.8472
286011.0359
287012.6380
288014.3190
289016.9874
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303063.8780
304065.5058
305067.2258
306068.9599
307071.0456
308073.4446
309074.8453
310075.3275
311078.3118
312088.0010
313095.7436
314095.1361
315078.5408
316074.1841
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319073.8814
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321067.2675
322066.0442
323066.6018
324065.1532
325060.8393
326057.3499
327055.6234
328055.8803
329054.1393
330050.1182
331046.6747
332044.9649
333045.0813
334044.2513
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339032.7606
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341027.7691
342026.5048
343025.9462
344024.6910
345022.5070
346020.5725
347019.5569
348019.0976
349018.1677
350016.6673
351015.1844
352014.3864
353014.0250
354013.3521
355012.0807
356011.0327
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363007.5352
364014.7558
365033.0470
366023.8414
367012.3363
368007.0350
369005.1119
INT.9 FROM
          250
     80.2453
SUNS =    26.2240
SUM FROM
          250
TO
          369
MILLIWATTS/MSQ
       3428.0341
SUM FROM
          270
TO
          290
MILLIWATTS/MSQ
        117.1260
SUM FROM
          290
TO
          320
MILLIWATTS/MSQ
       1880.9138
SUM FROM
          320
TO
          340
MILLIWATTS/MSQ
       1059.7177
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Fig. 2. Typical UV spectra

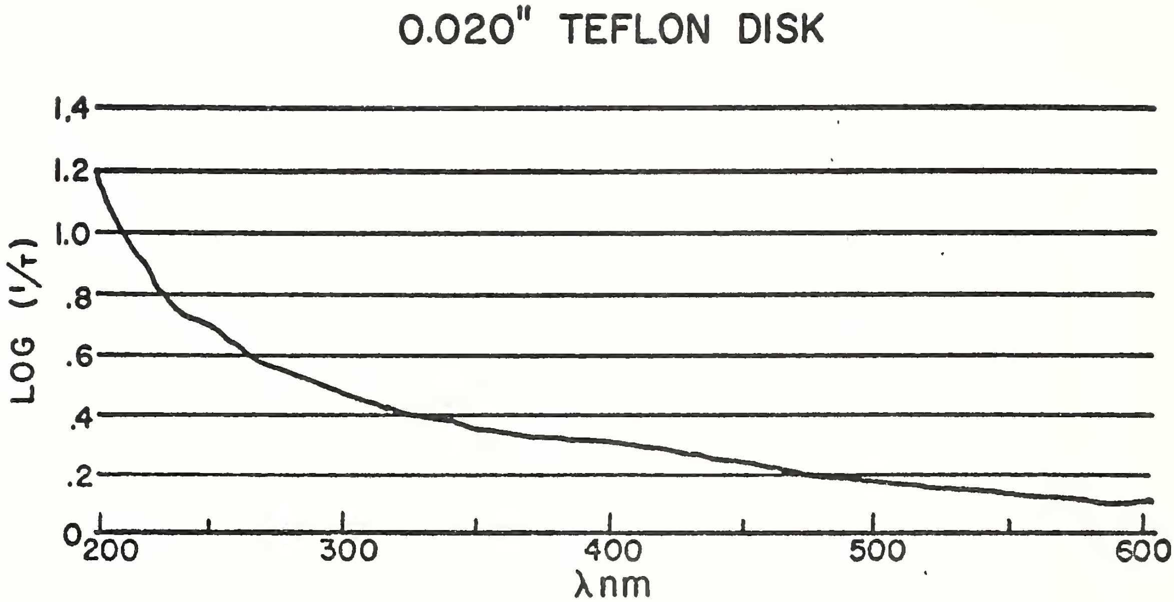

Fig. 3. Teflon spectral transmission

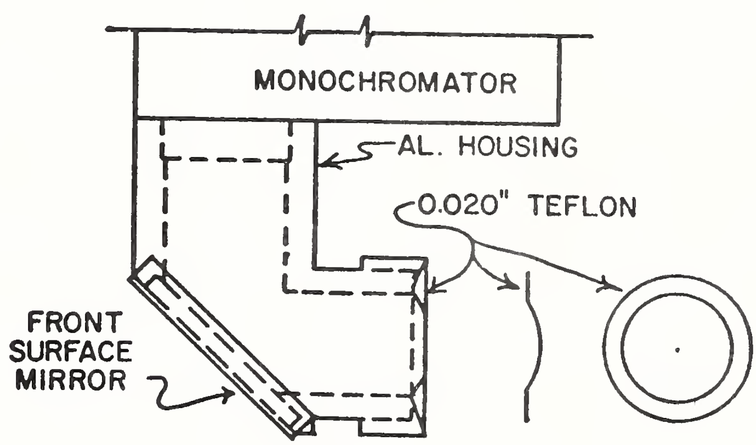

Fig. 4. IRLSpec-S RECEPTOR OPTICS

3-31-77

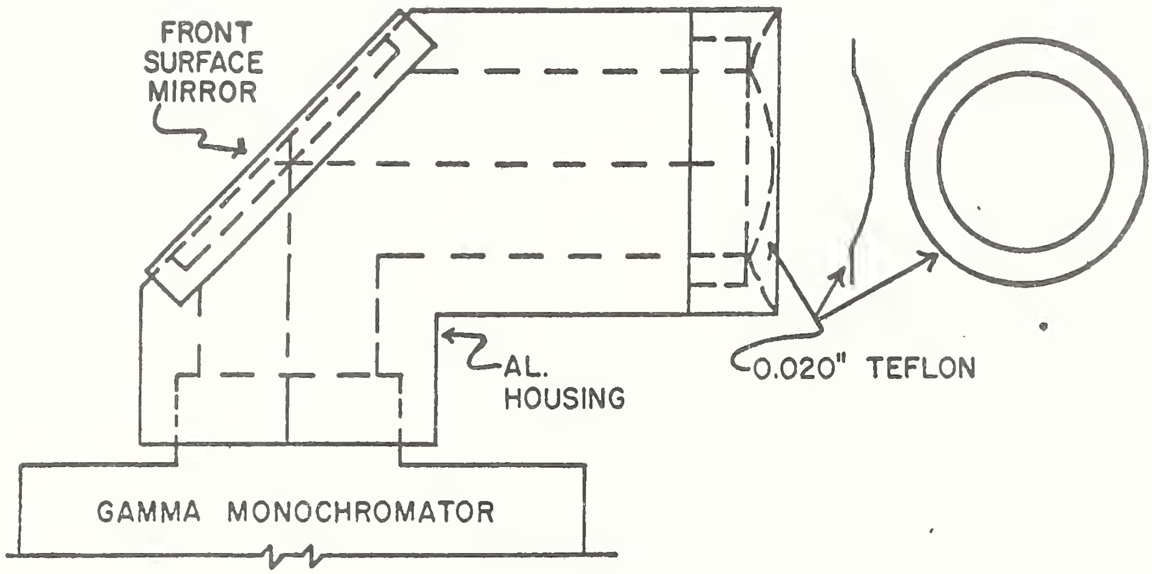

Fig. 5. IRL RECEPTOR OPTICS FOR GAMMA

3-31-77

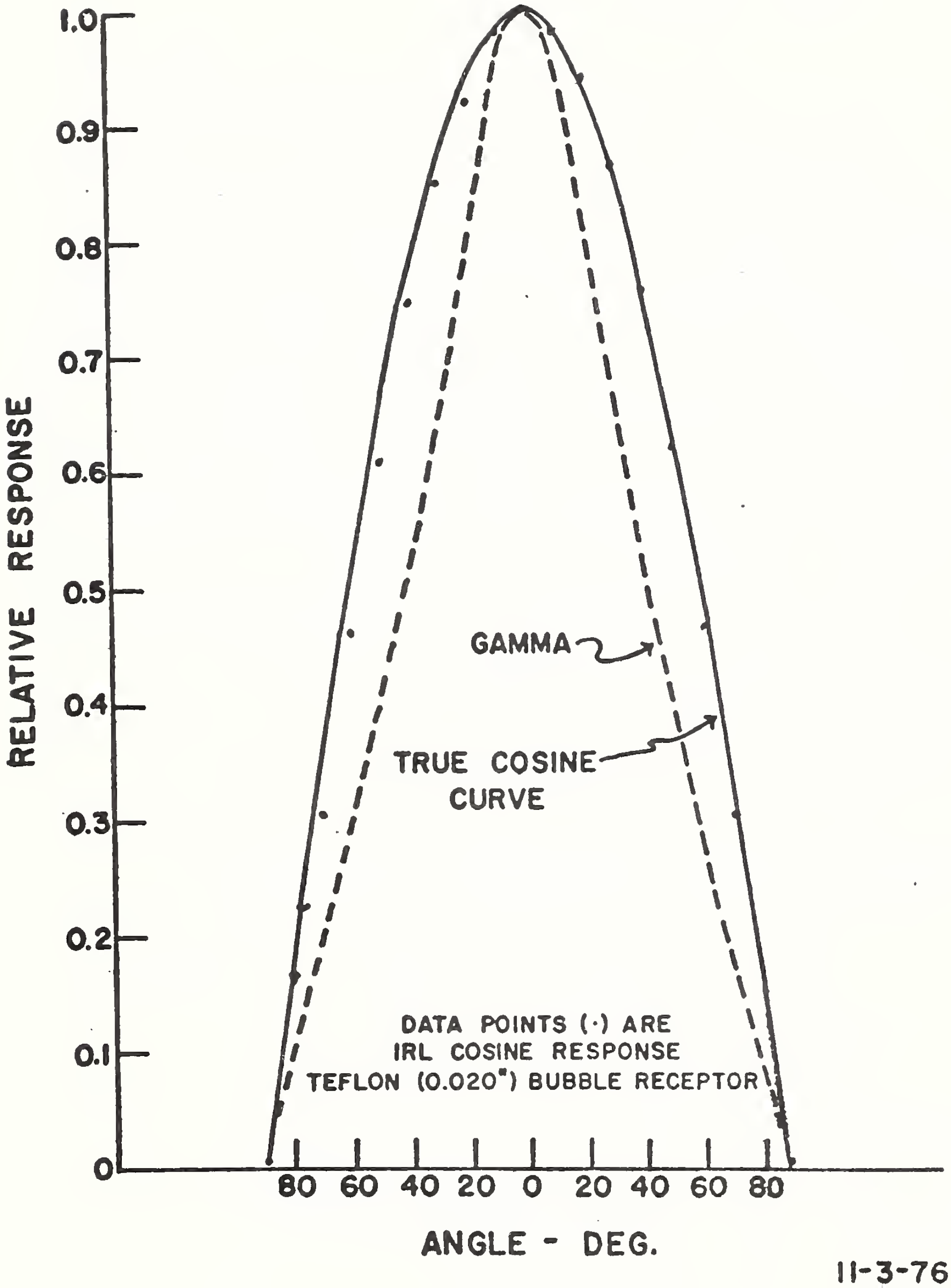

Fig. 6. Receptor cosine response

```
A RUN SPECTRA
B REVERSE
D RECORD DATA
E STOP
F FORWARD
G PRINT DATA
I INT. 9
J W. L. CHECK
M SUMS
N DARK ADJUST
 DATE
  2780203.00
W. L. CAL.

  2780203.01

 2940002.164
 2950020.760
 2960043.339
 2970047.488
 2980029.693


MERCURY LINE AT
     296.738

W. L. CAL.

  2780203.02

 2940002.189
 2950020.965
 2960043.339
 2970047.444
 2980029.864


MERCURY LINE AT
     296.736

W. L. CAL.

  2780203.03

 2940002.155
 2950020.933
 2960043.419
 2970047.576
 2980030.002


MERCURY LINE AT
     296.738

W. L. CAL.

  2780203.04

 2940002.136
 2950020.800
 2960042.259
 2970047.510
 2980030.015


MERCURY LINE AT
     296.739

W. L. CAL.

  2780203.05

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 2950020.808
 2960043.319
 2970047.532
 2980030.210


MERCURY LINE AT
     296.742

W. L. CAL.

  2780203.06

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 2950020.765
 2960043.333
 2970047.488
 2980029.754


MERCURY LINE AT
     296.738

W. L. CAL.

  2780203.07

 2940002.192
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 2960043.419
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 2980029.117


MERCURY LINE AT
     296.721
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Fig. 7. Hg line wavelength check - IRLSpec-D

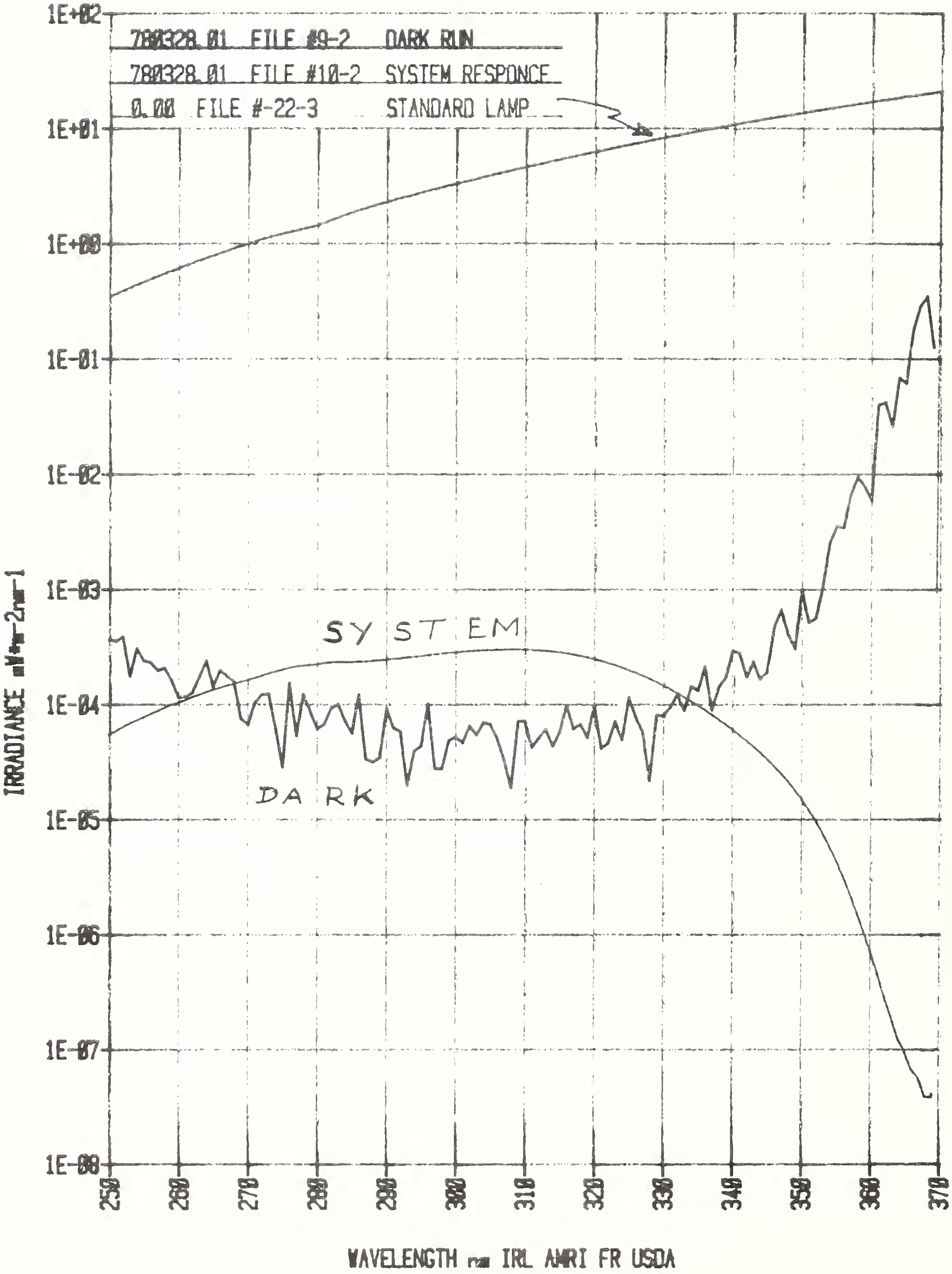

Fig. 8. IRLSpec-S sensitivity and dark current

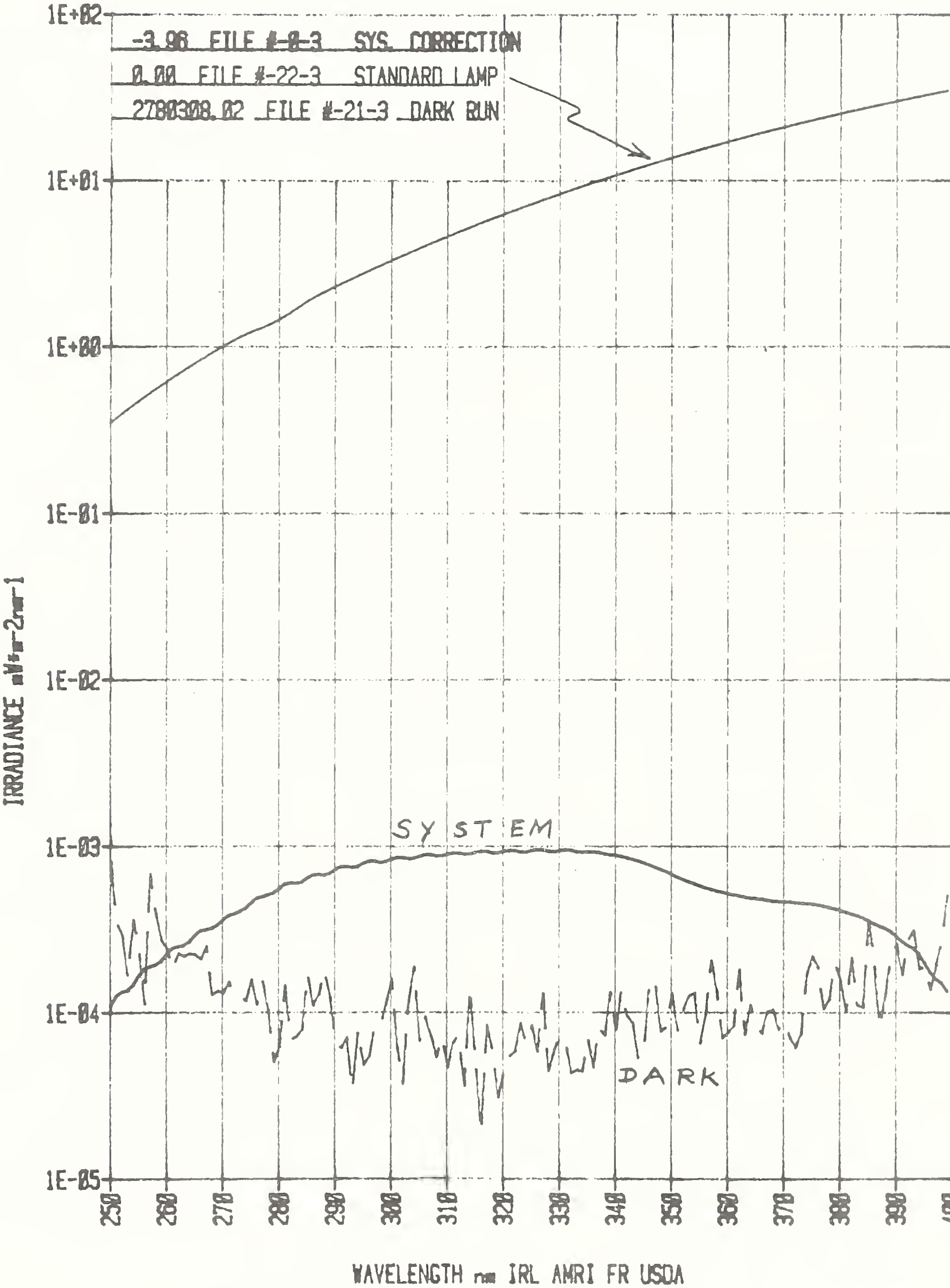

Fig. 9. IRLSpec-D sensitivity and dark current

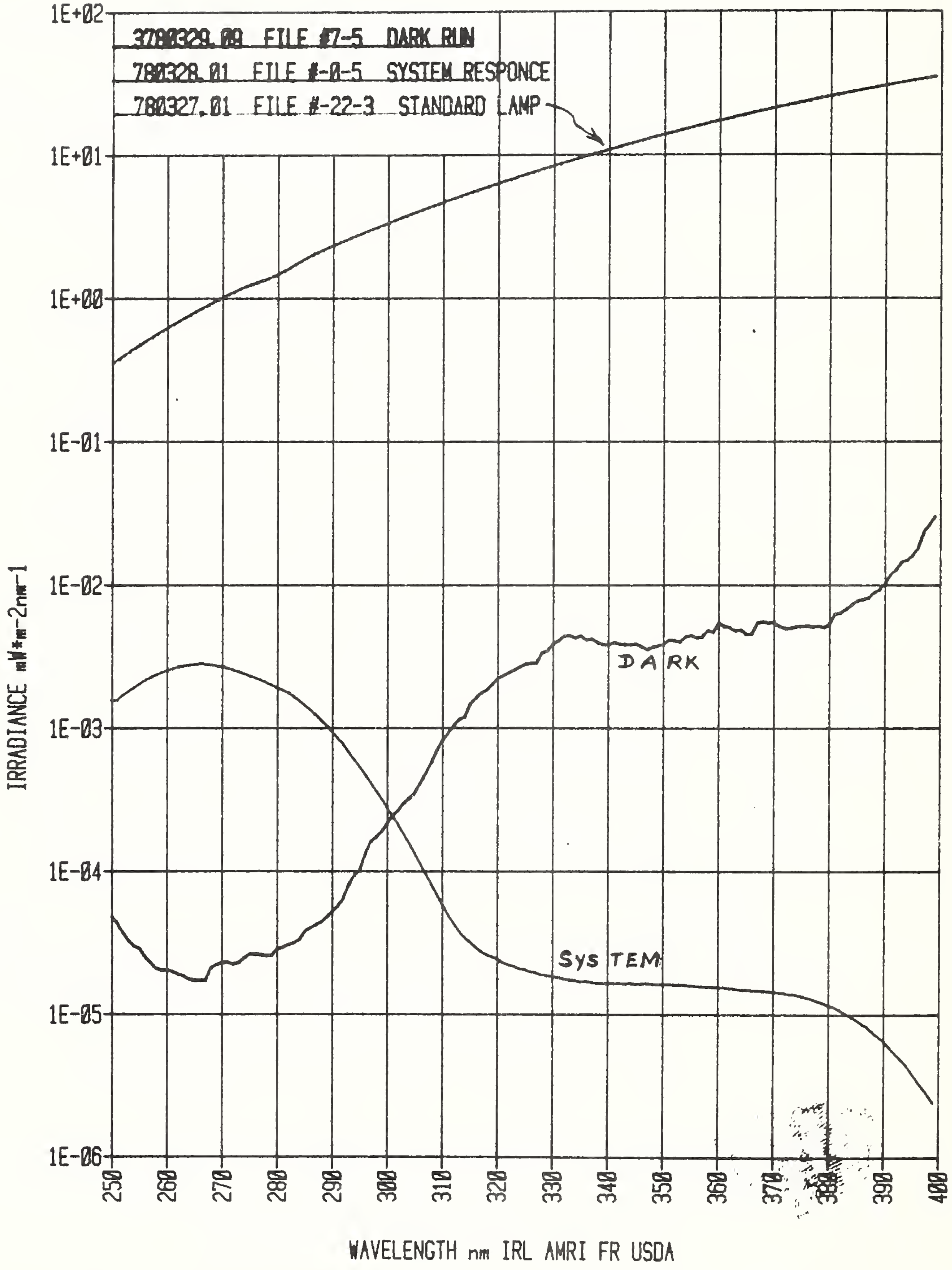

Fig. 10. IRLSpec-SO sensitivity and dark current

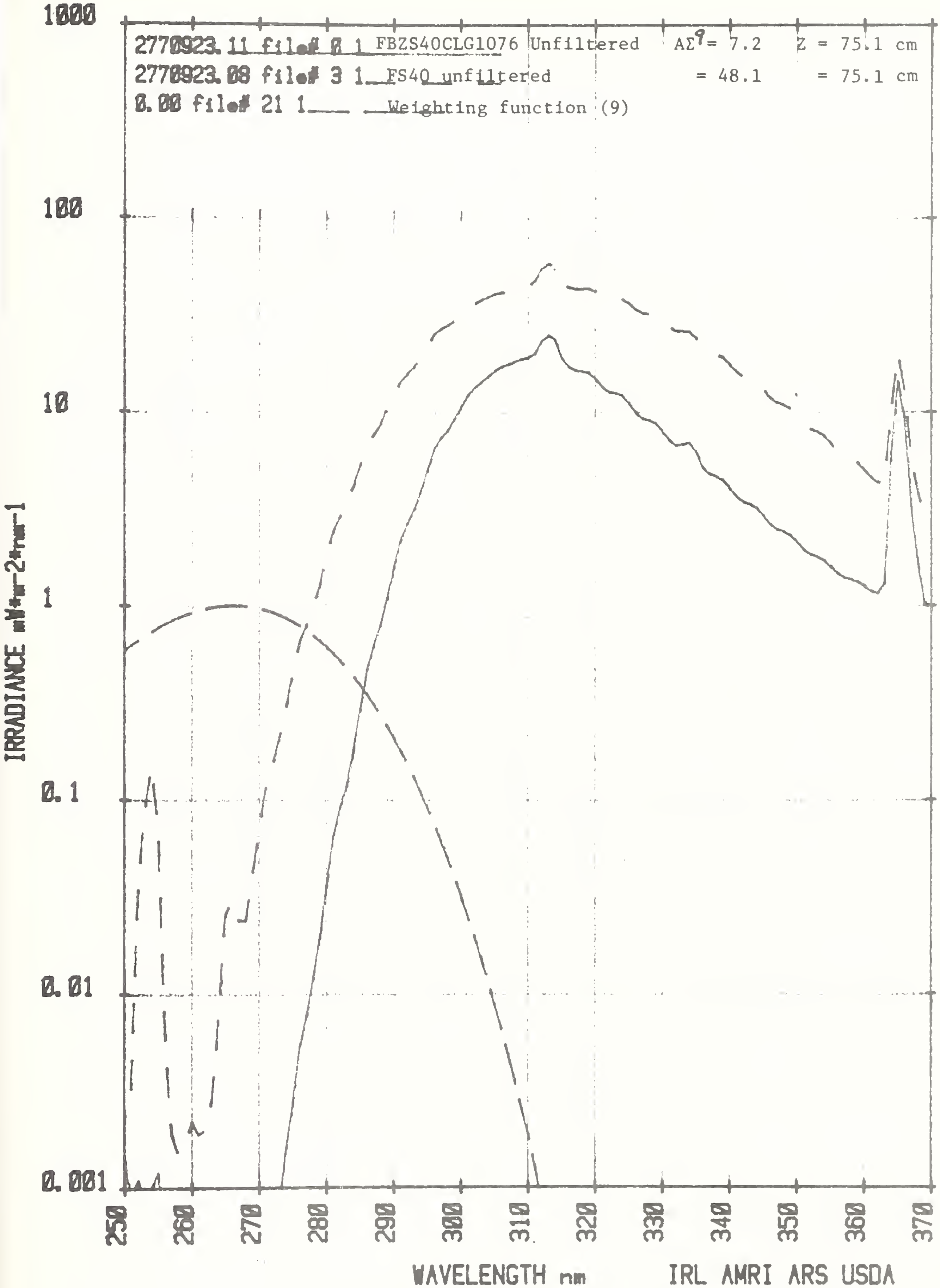

Fig. 11 Lamp spectra (unfiltered) FS40, FBZS40CLG1076 and weighting function 9

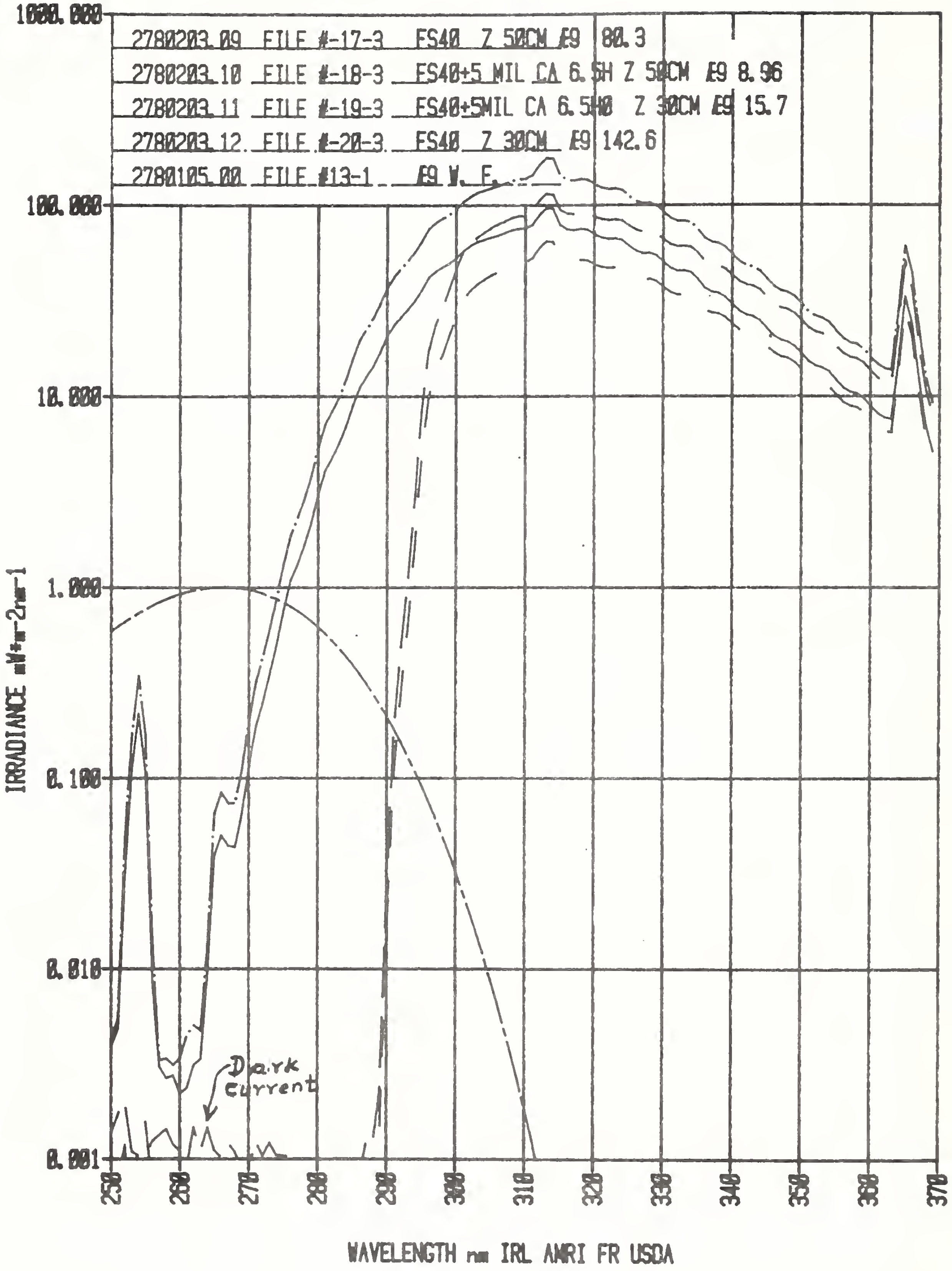

Fig. 12 Lamp spectra FS40 and cellulose acetate 6.5 hr. Z = 30cm, Z = 50cm

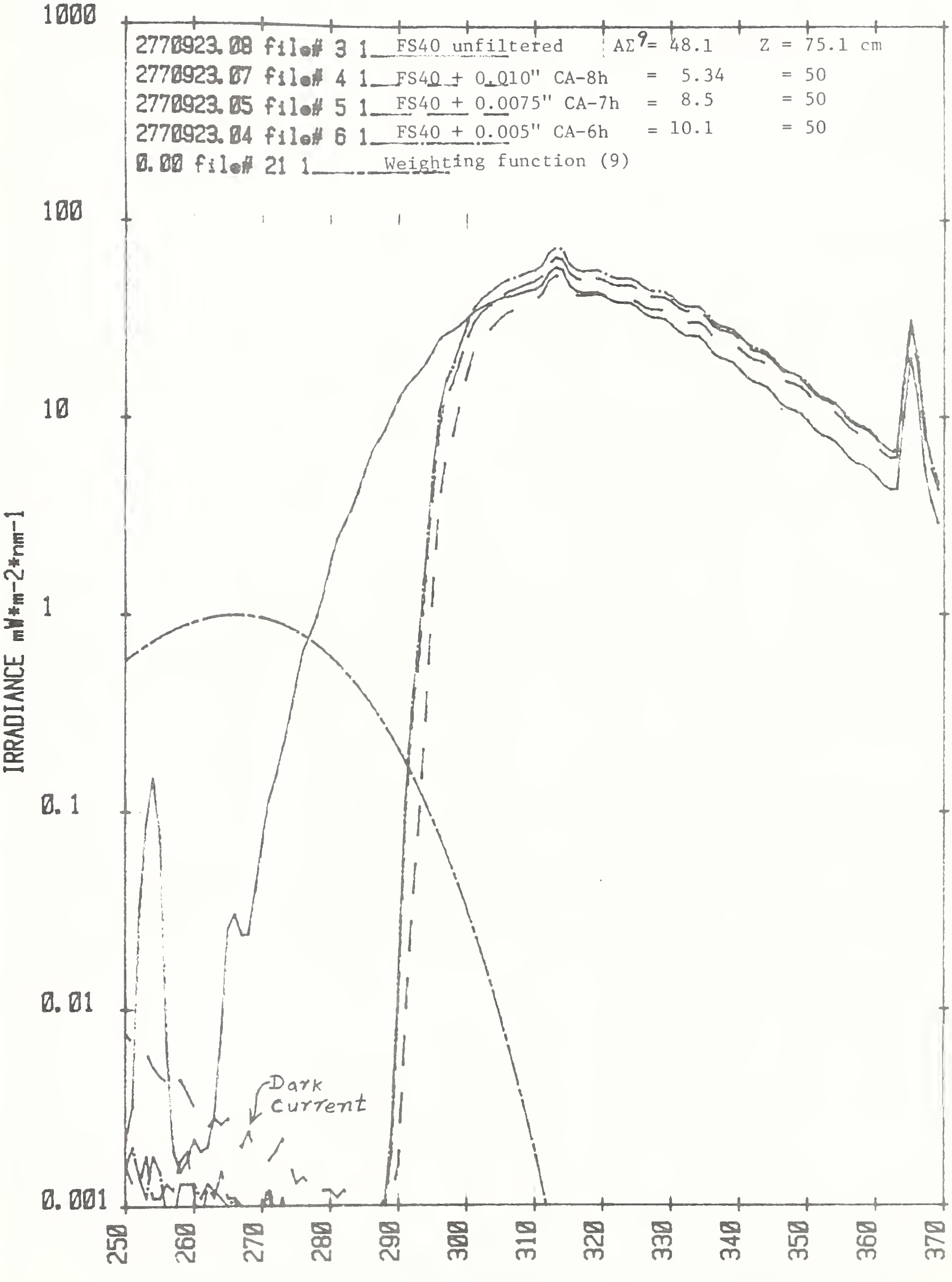

Fig. 13 Lamp spectra FS40 and 0.127 mm, 0.191 mm, 0.254 mm cellulose acetate

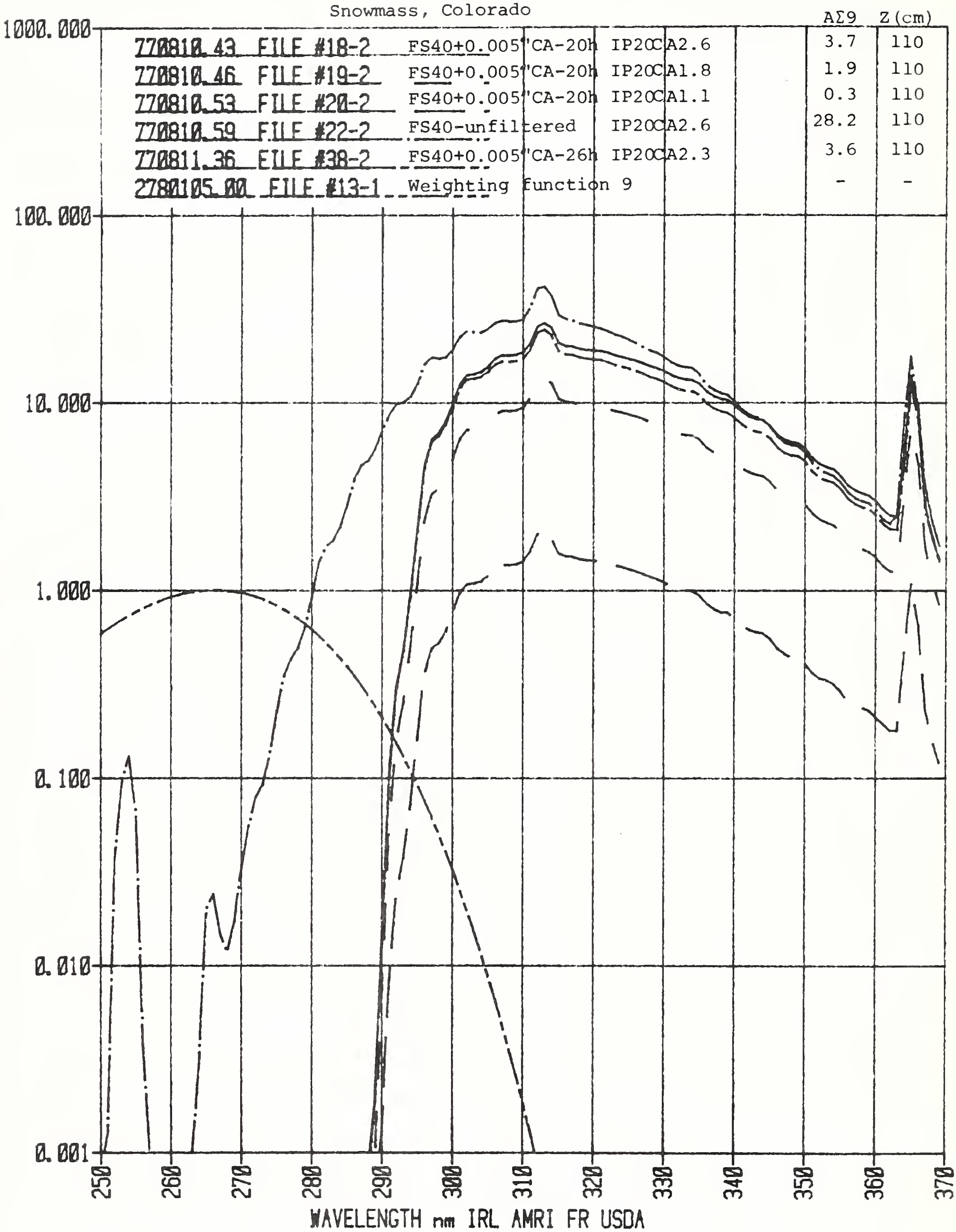

Fig. 14. Lamp spectra, Snowmass, Colorado

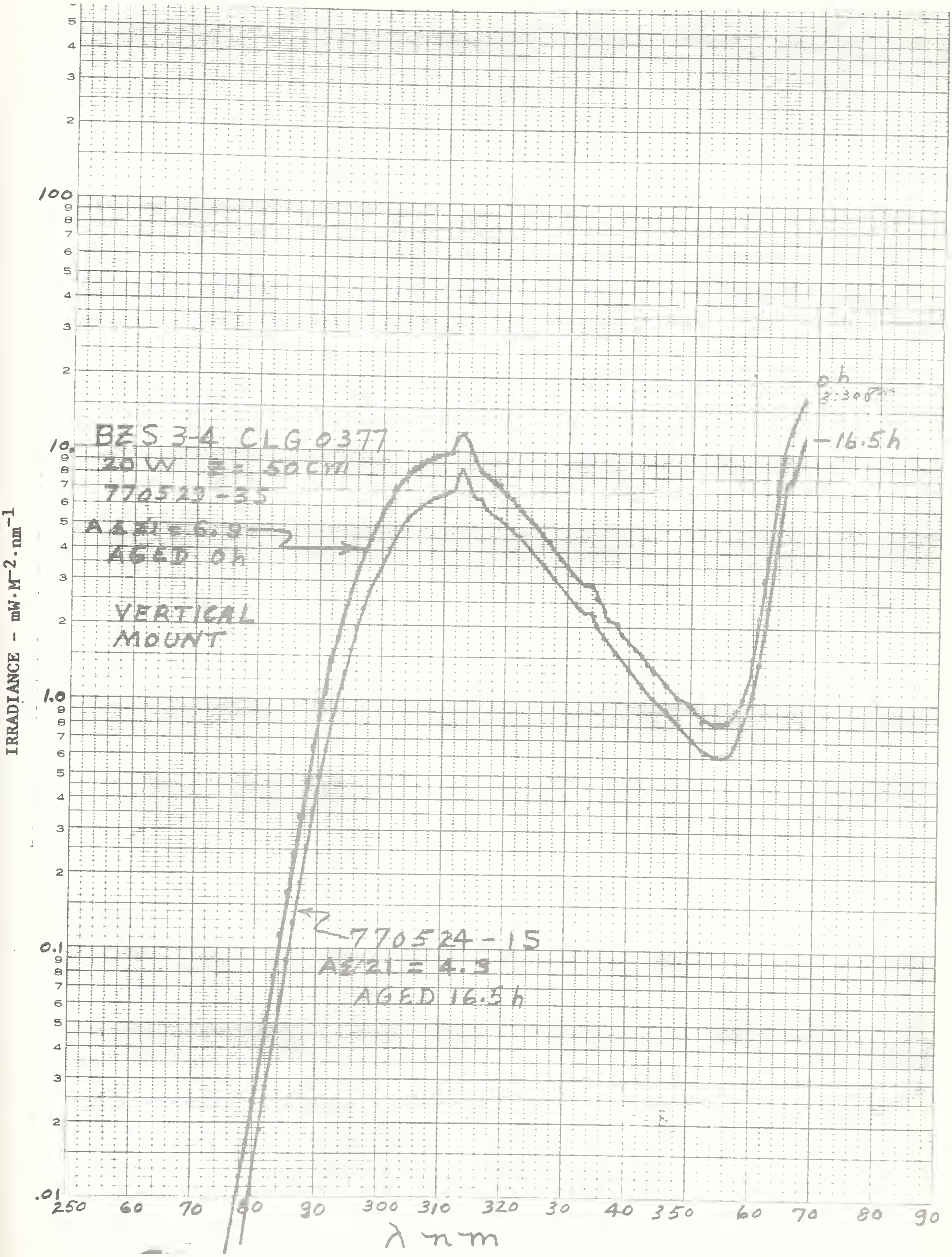

Fig. 15. Lamp aging - BZS 20 CLG0377

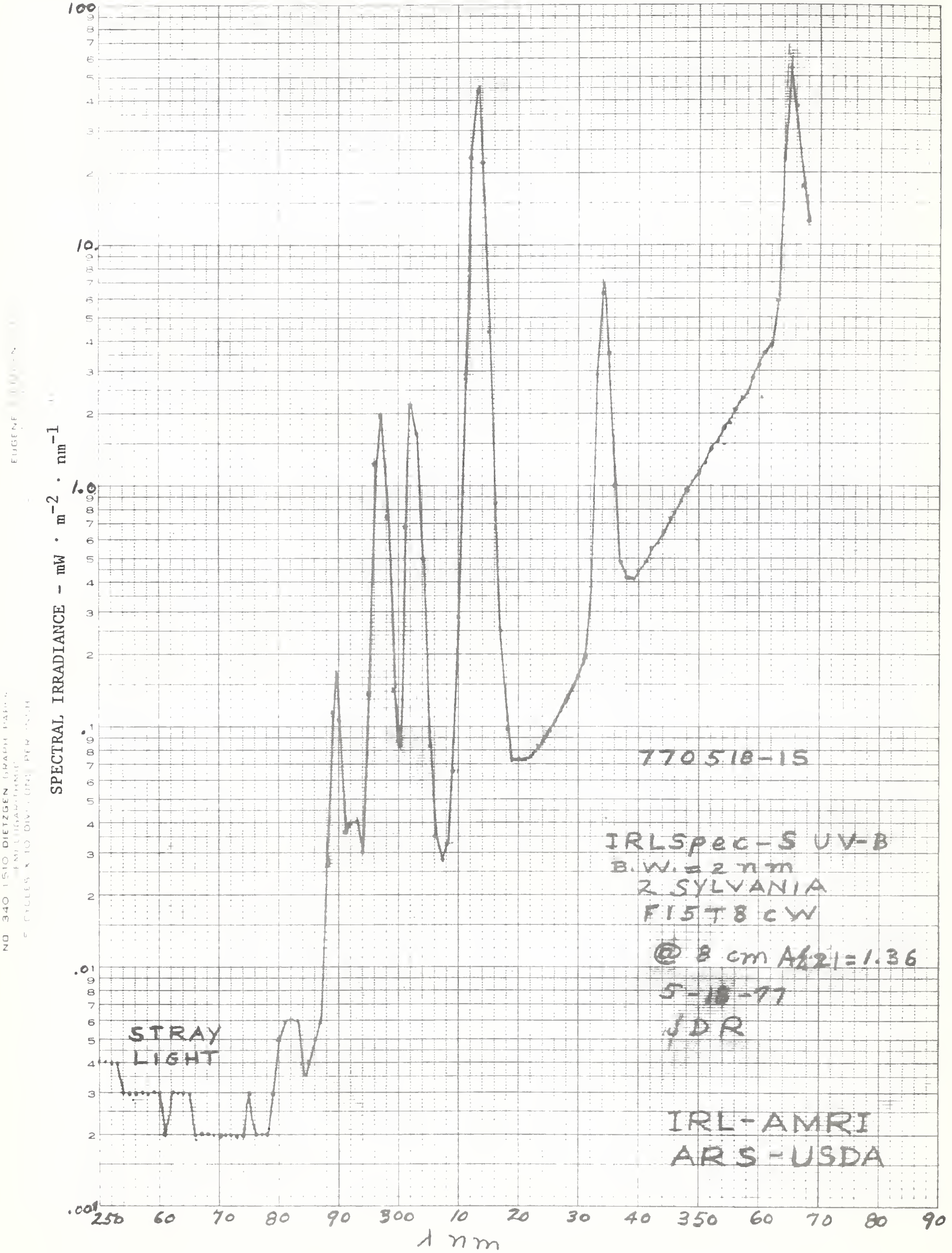

Fig. 16 Sylvania F15T8 CW lamp spectra - IRLSpec-S

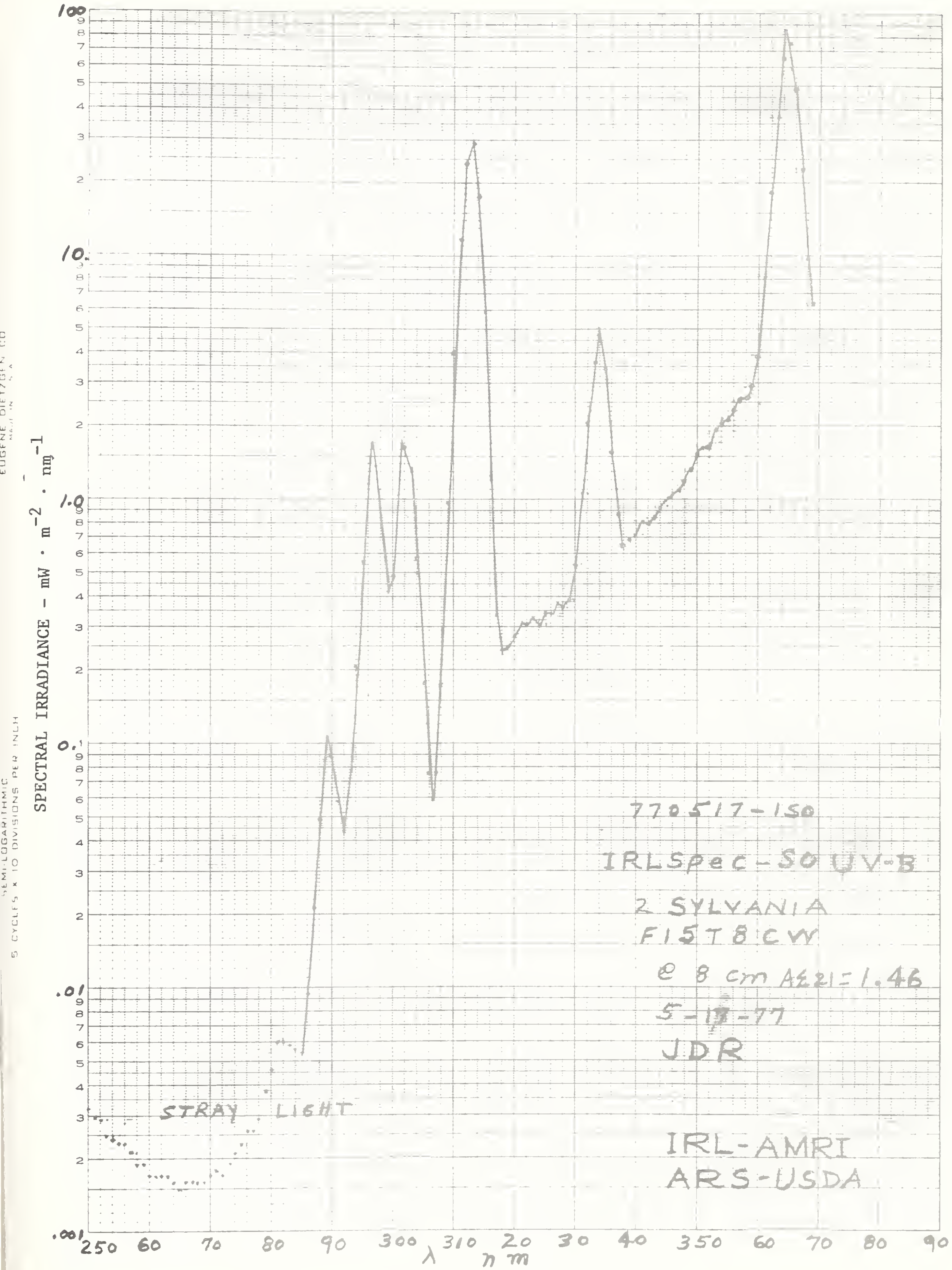

Fig. 17. Sylvania F15T8 CW lamp spectra IRLSpec-SO

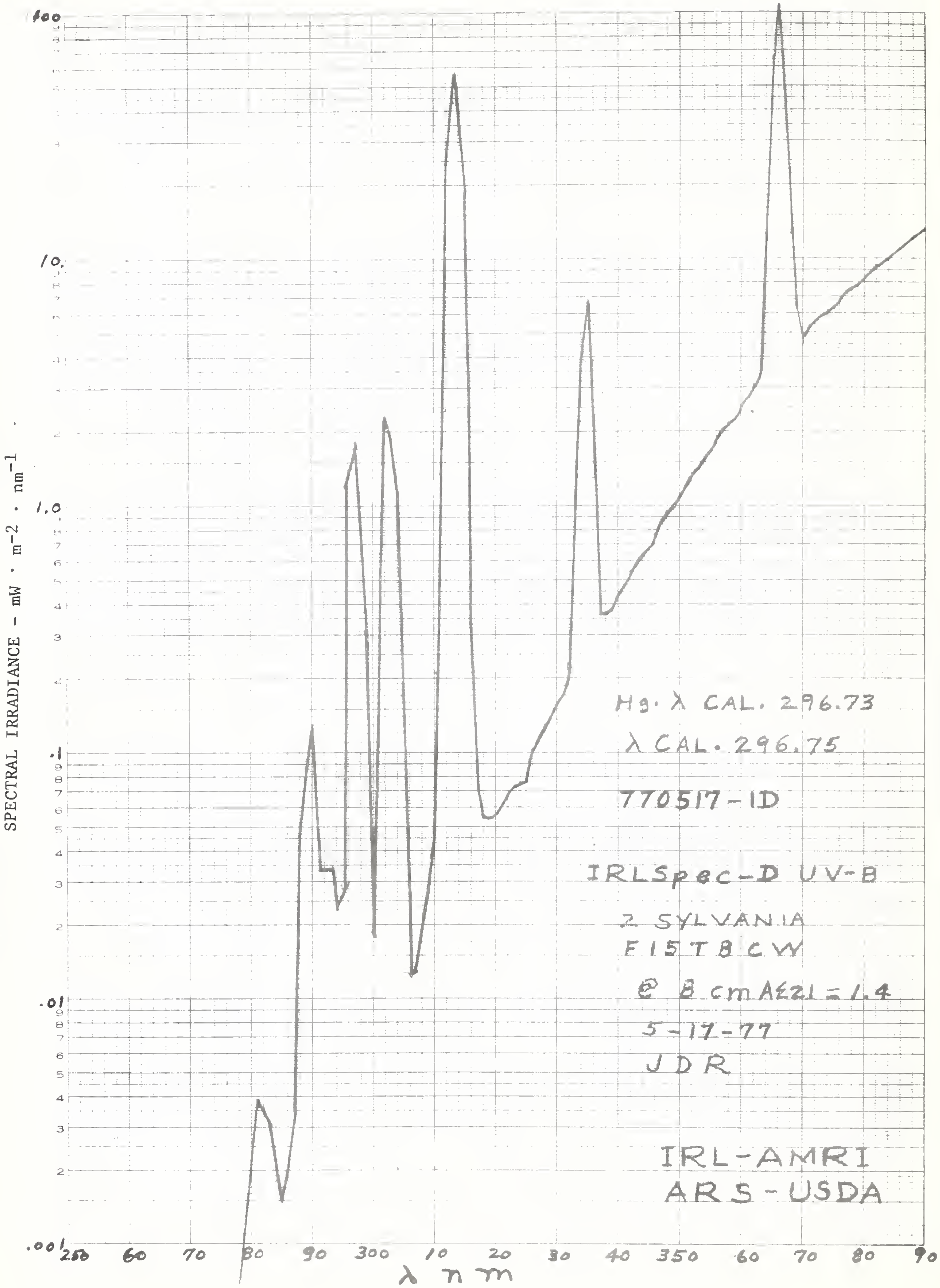

Fig. 18. Sylvania F15T8 CW lamp spectra IRLSpec-D

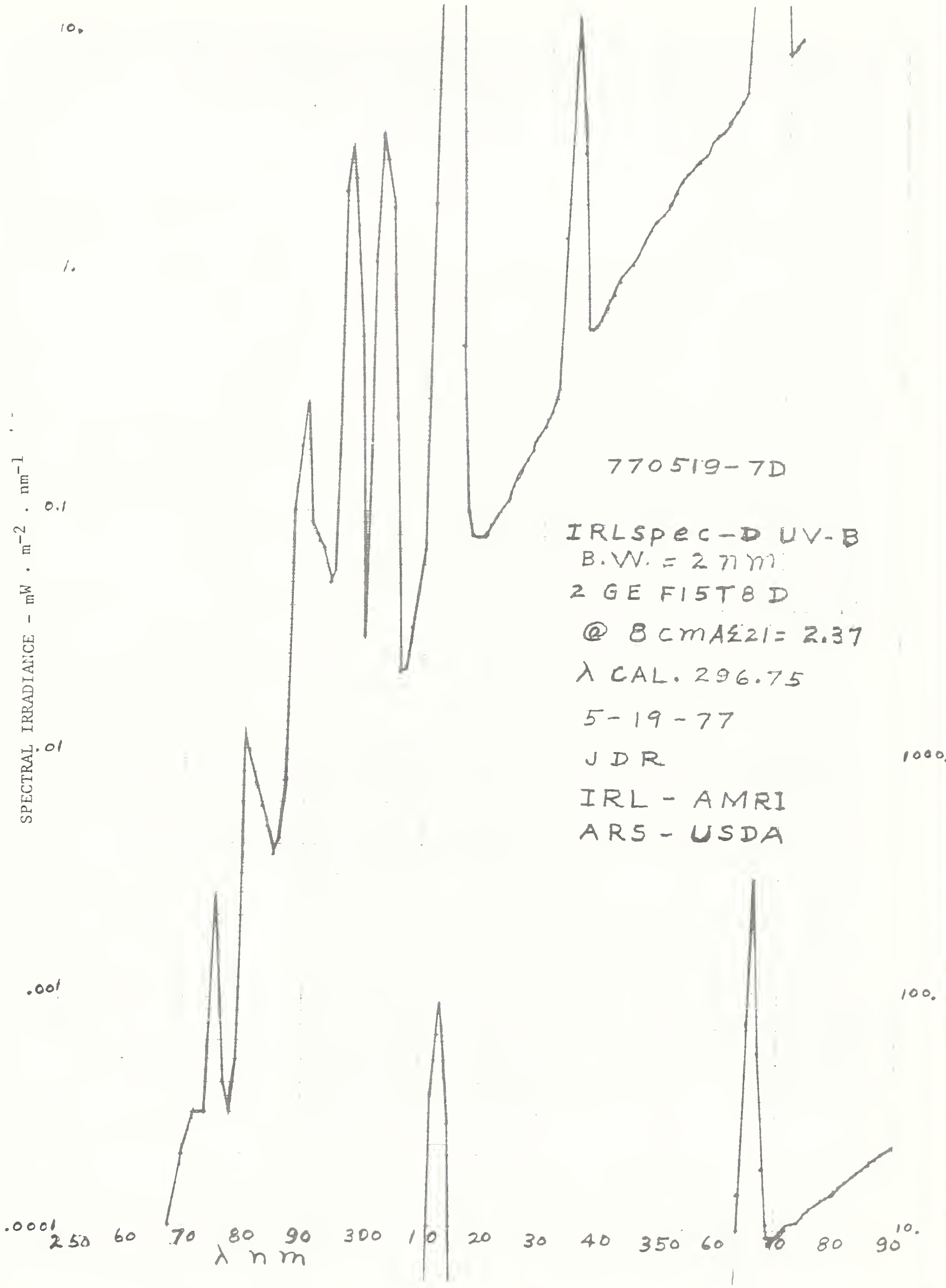

Fig. 19. GE F15T8D lamp spectra IRLSpec-D

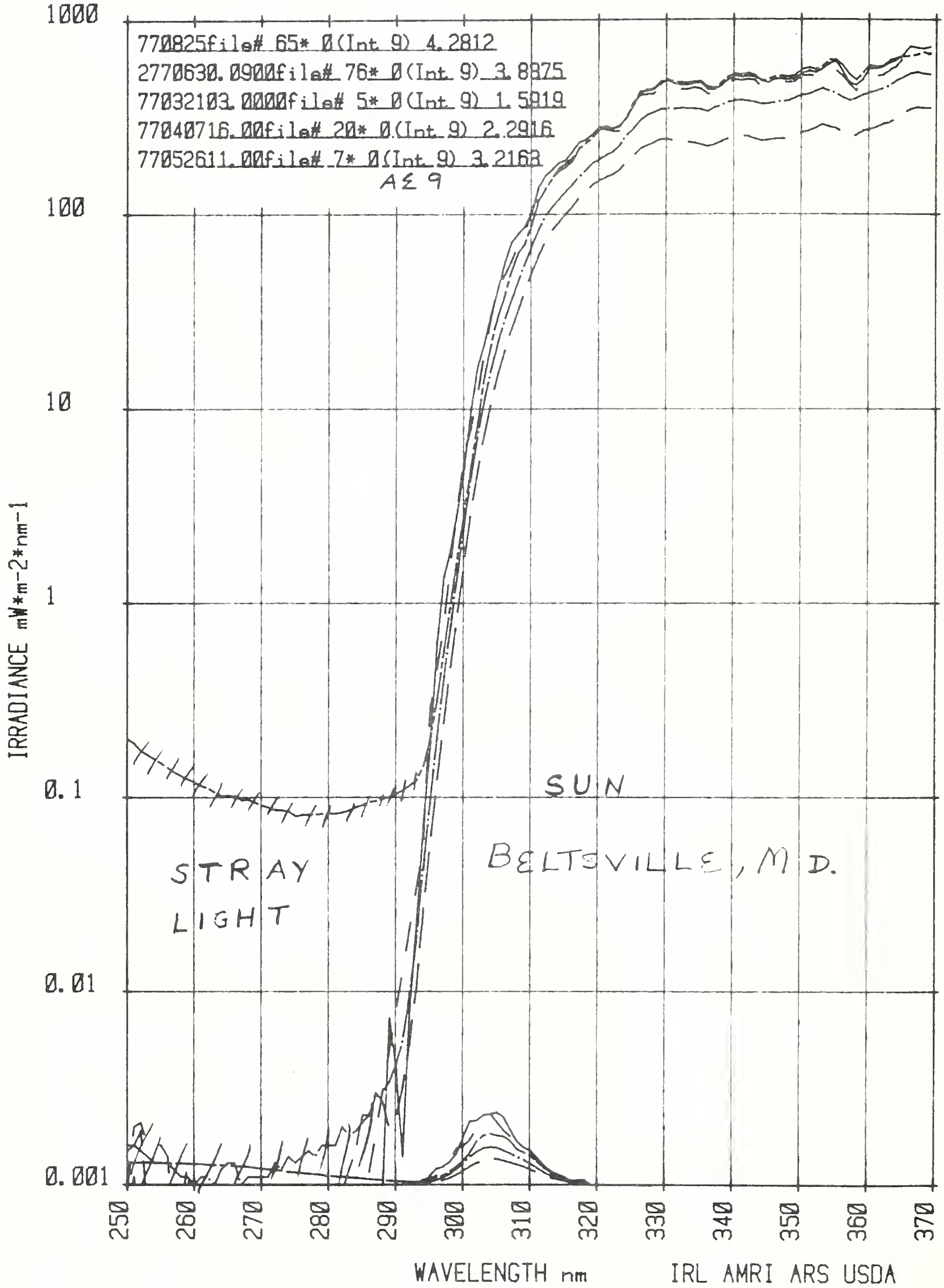

Fig. 20. Sun spectra - Beltsville, MD

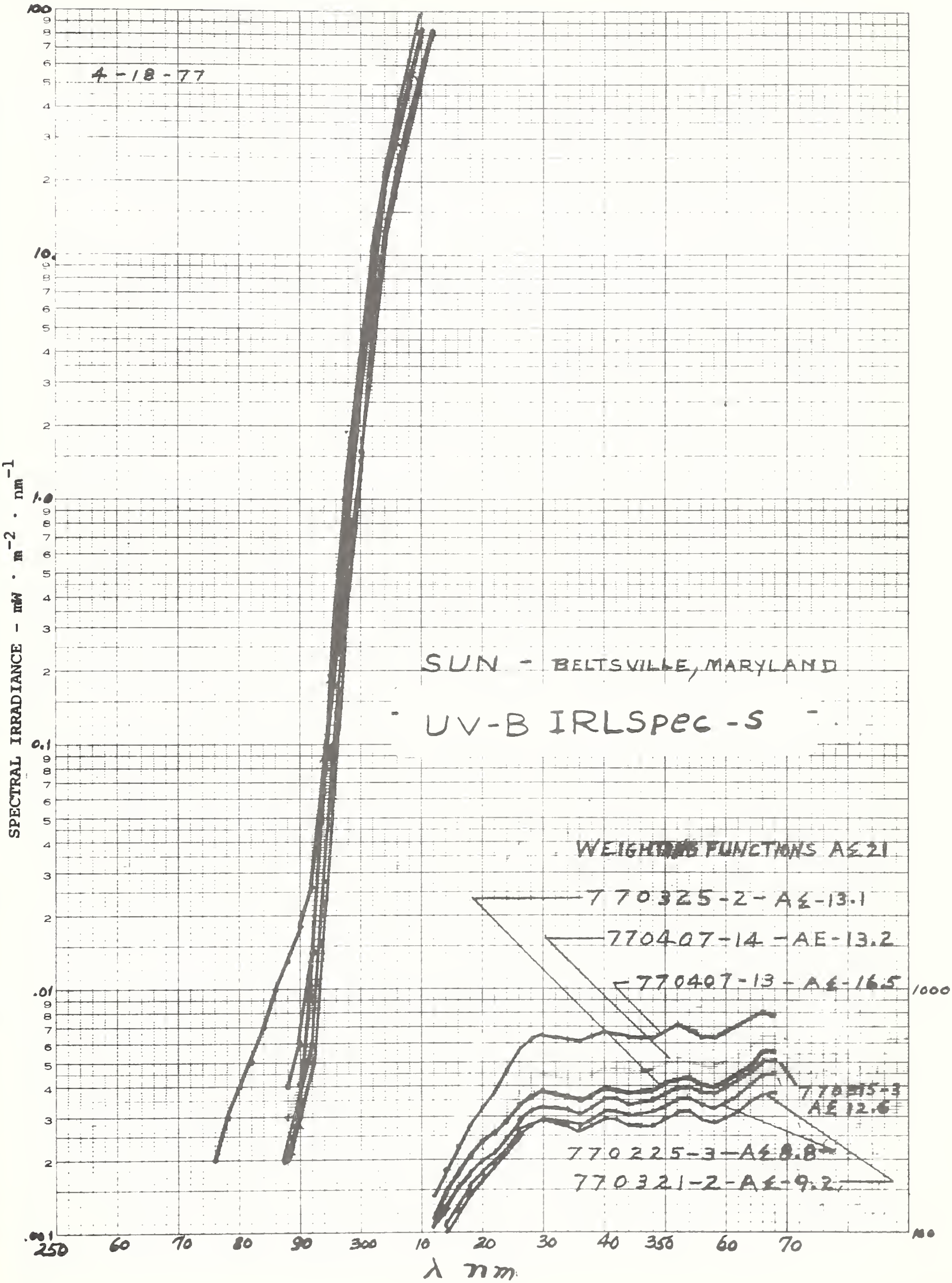

Fig. 21. Sun spectra - Beltsville, MD - IRLSpec-S

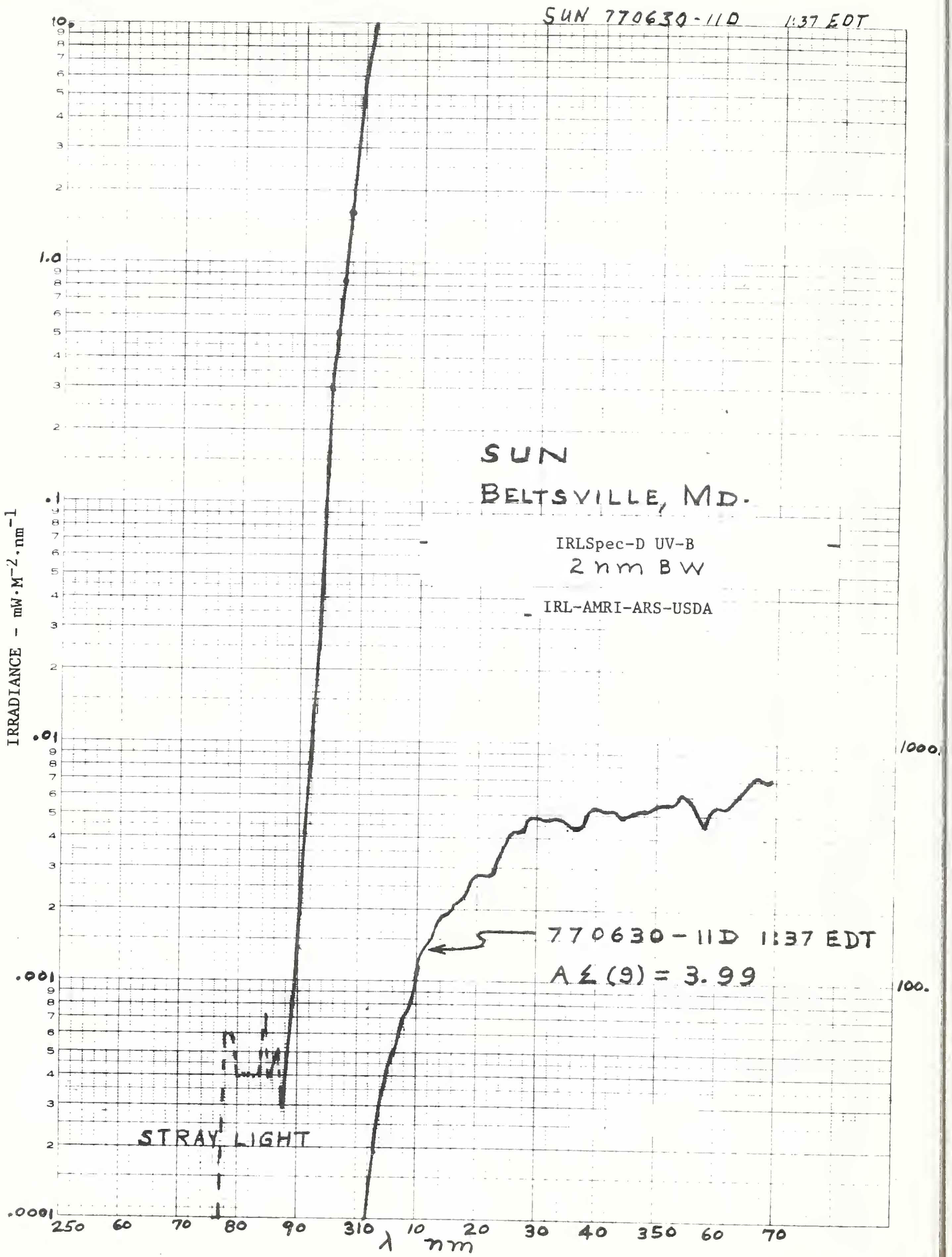

Fig. 22. Sun - Beltsville, MD - IRLSpec-D

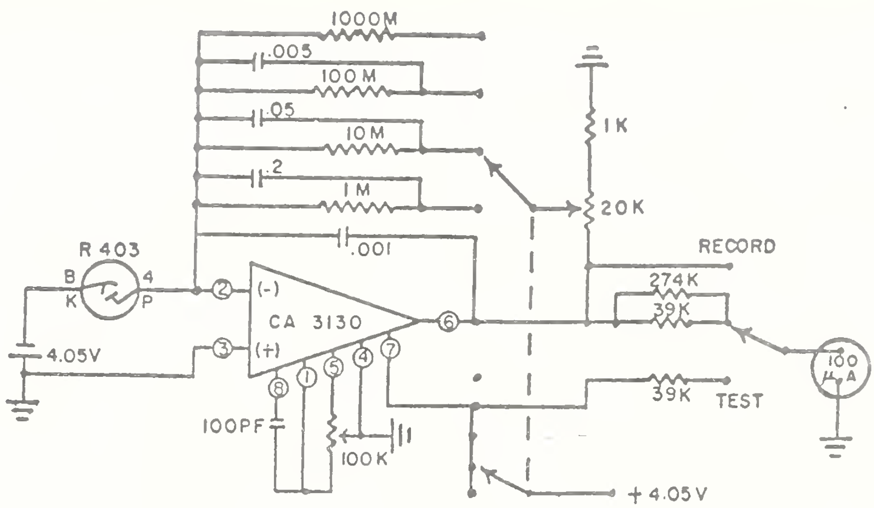

Fig. 23. UV-B IRL METER CIRCUIT

2-7-77

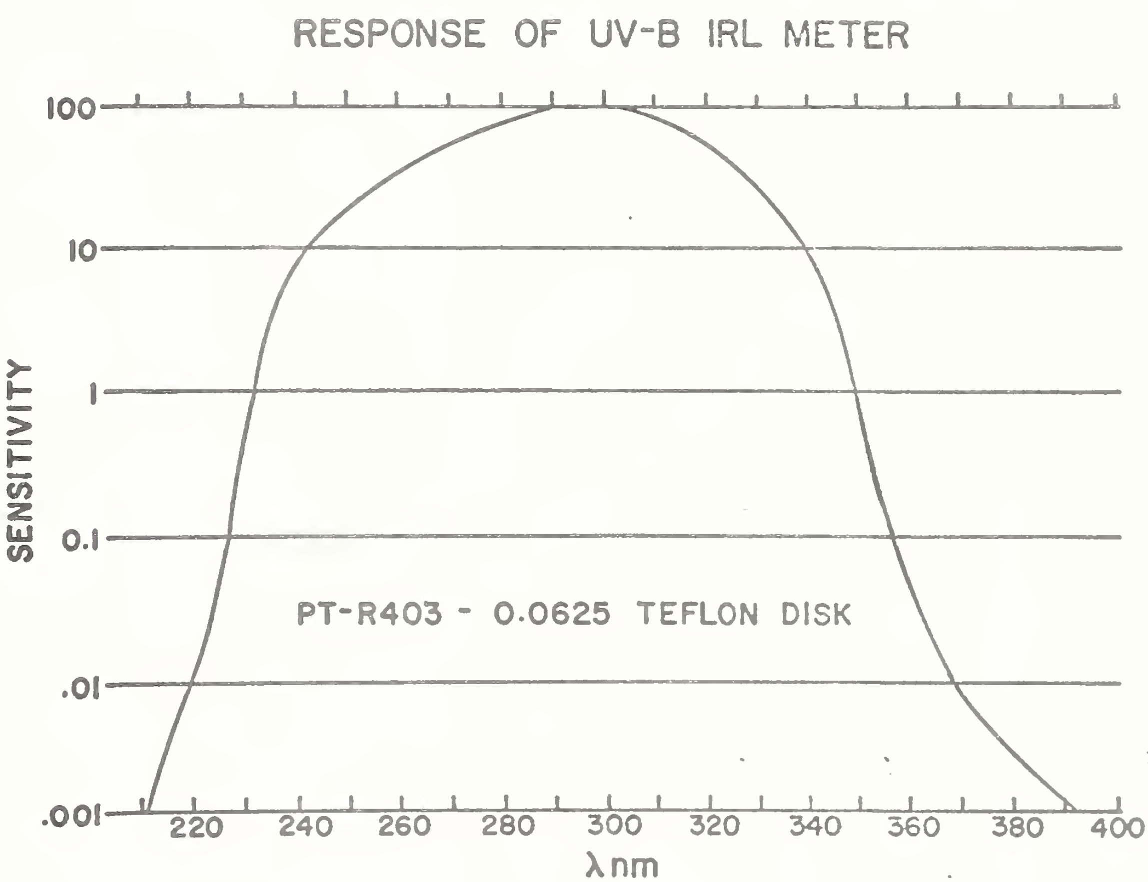

Fig. 24. IRLMeter spectral response

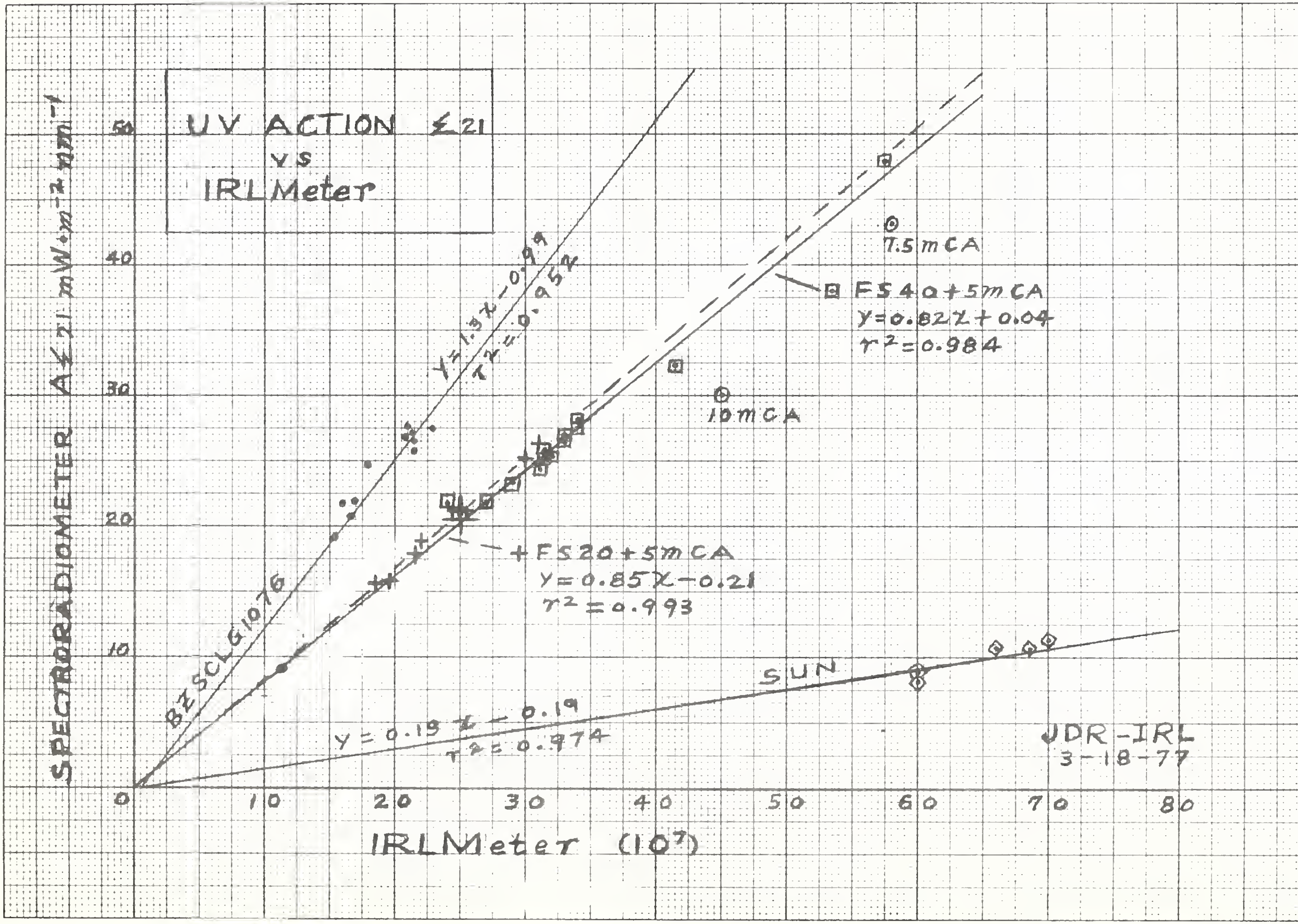

Fig. 25. Regression IRLSpec-S vs. IRLMeter

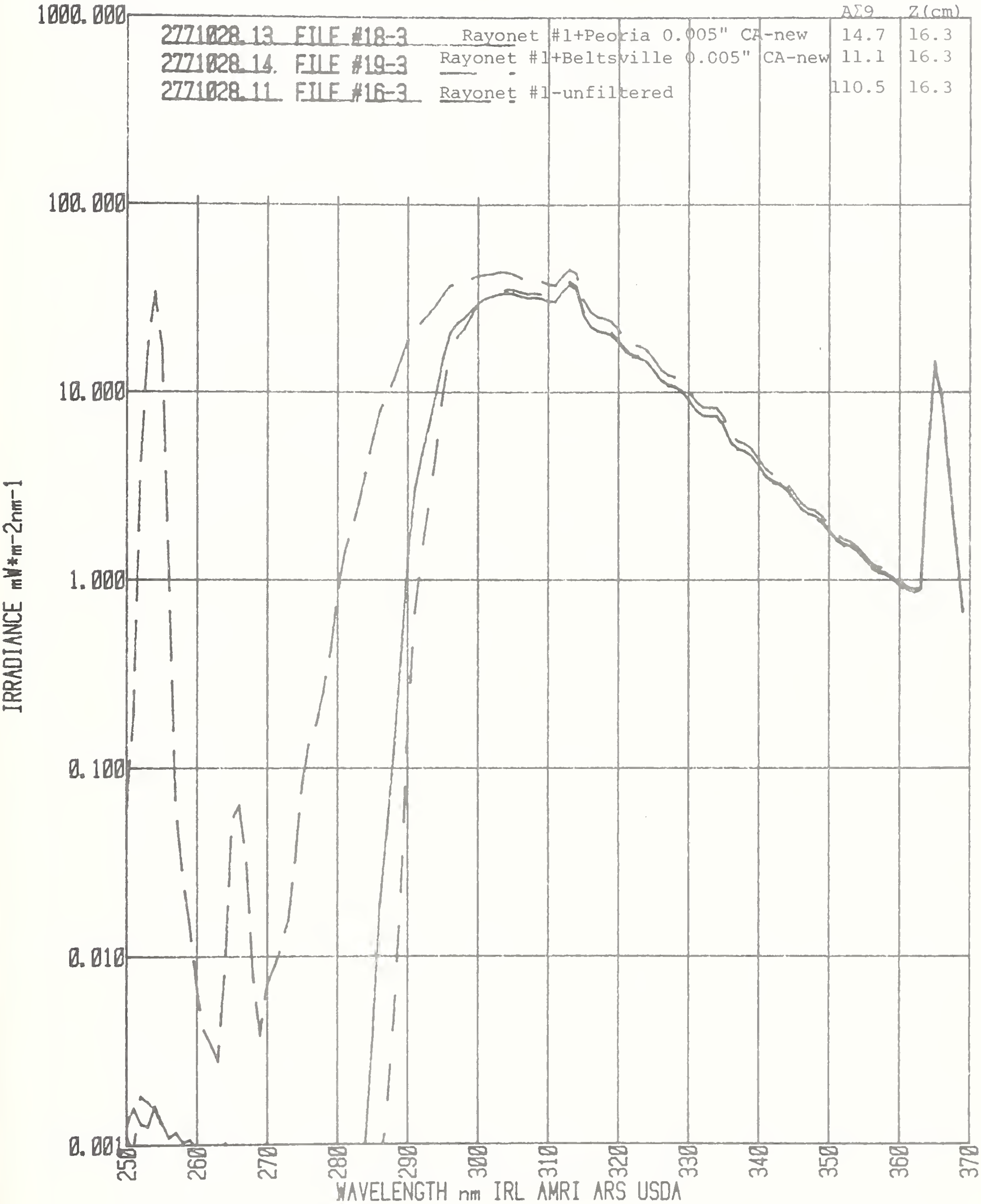

Fig. 26. Rayonet F8T5 RPR 3000A^{o} spectra new cellulose acetate, Z = 16.3 cm

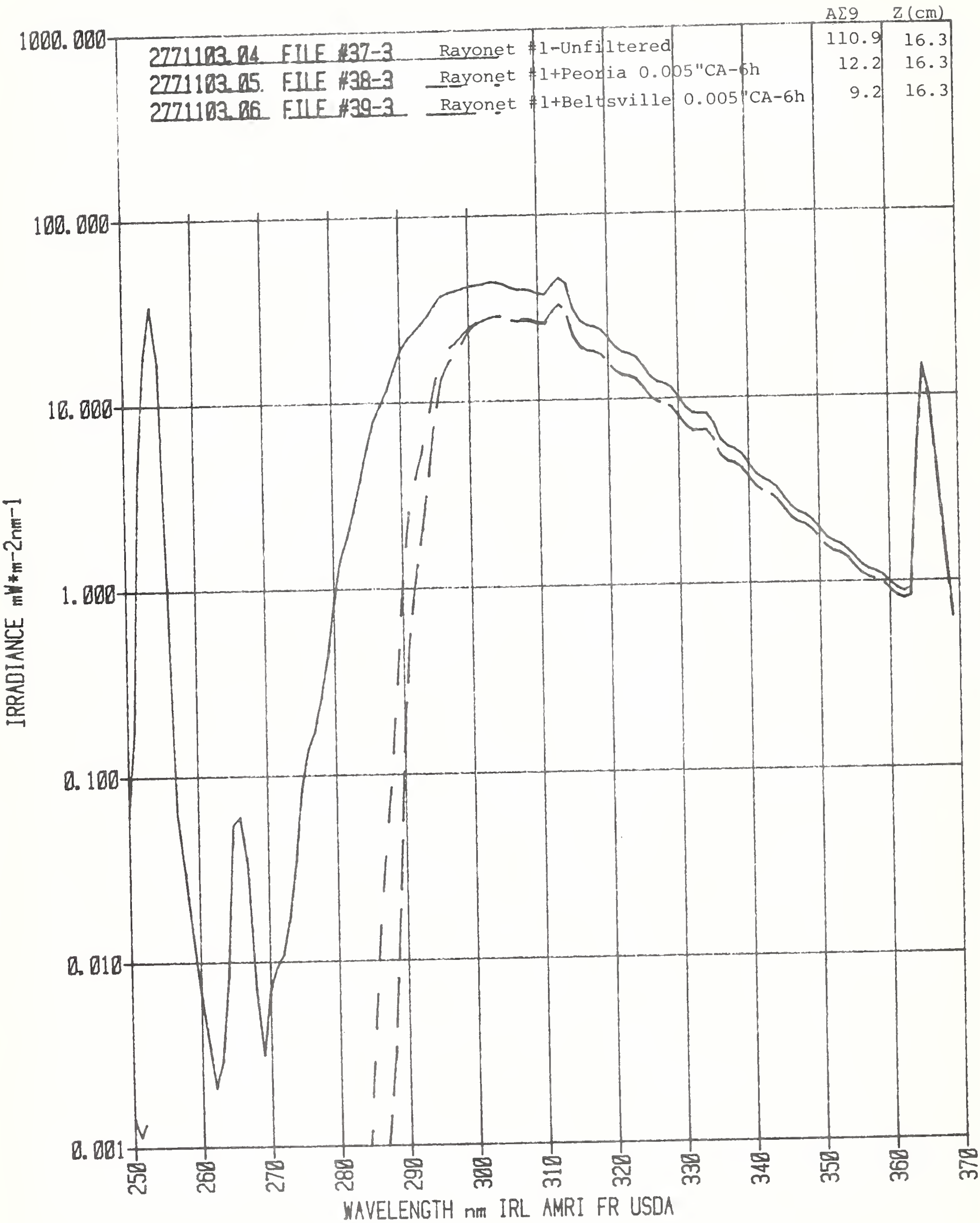

Fig. 27. Rayonet F8T5 RPR 3000A° spectra cellulose acetate aged 6 hr., Z = 16.3 cm

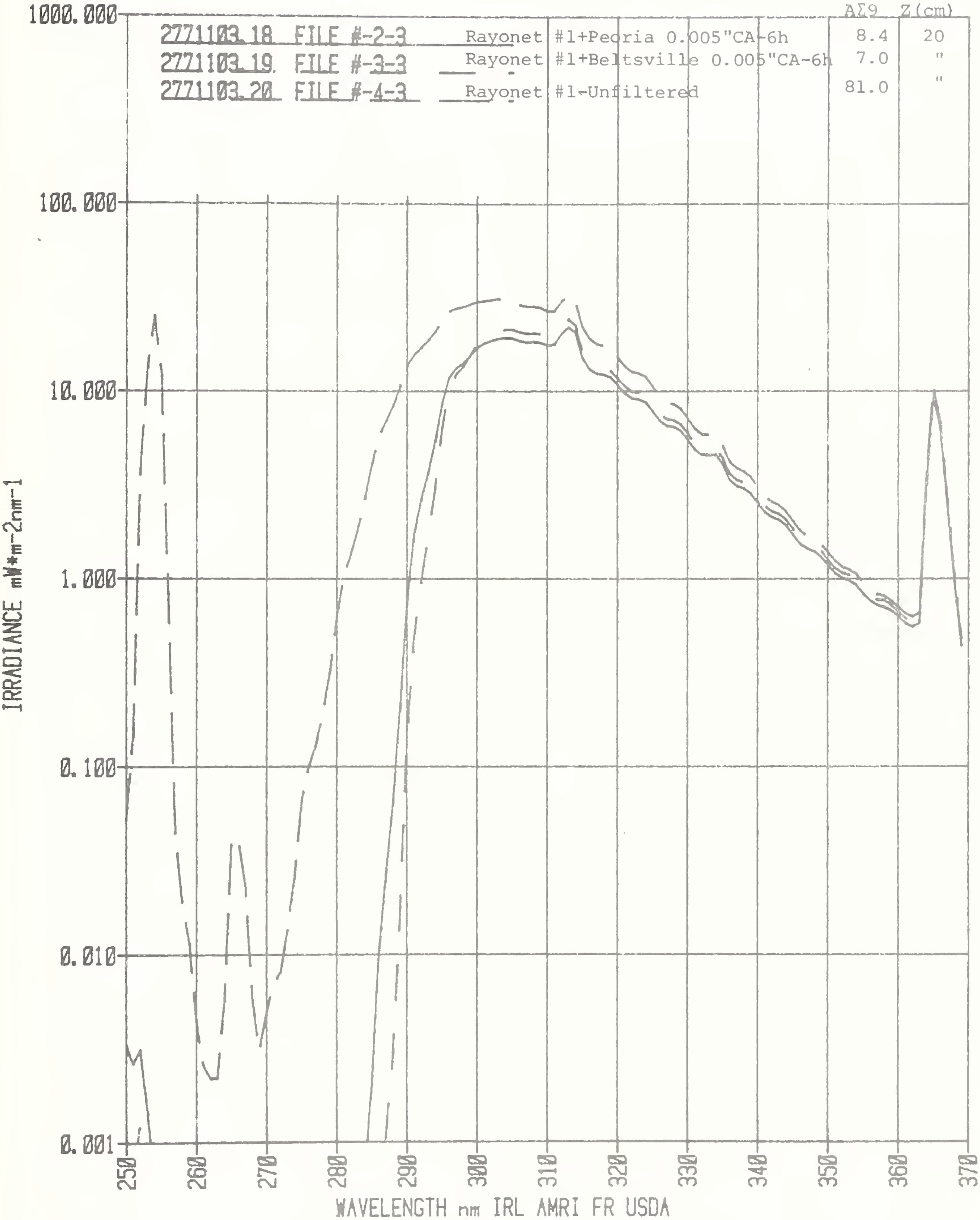

Fig. 28. Rayonet F8T5 RPR 3000A° spectra cellulose acetate aged 6 hr. Z = 20 cm

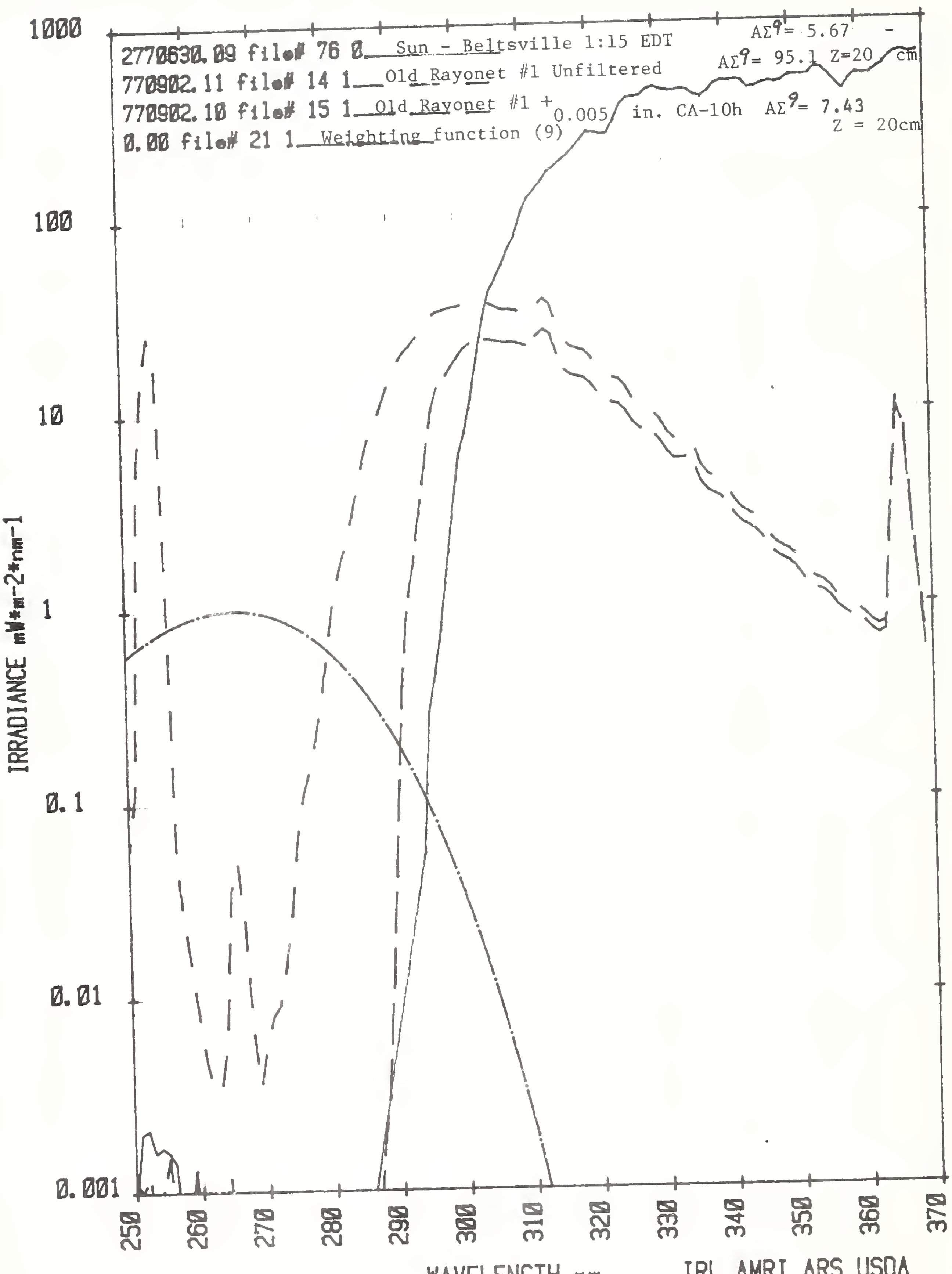

Fig. 29. Rayonet F8T5 RPR 3000A° and sun (Beltsville) spectra

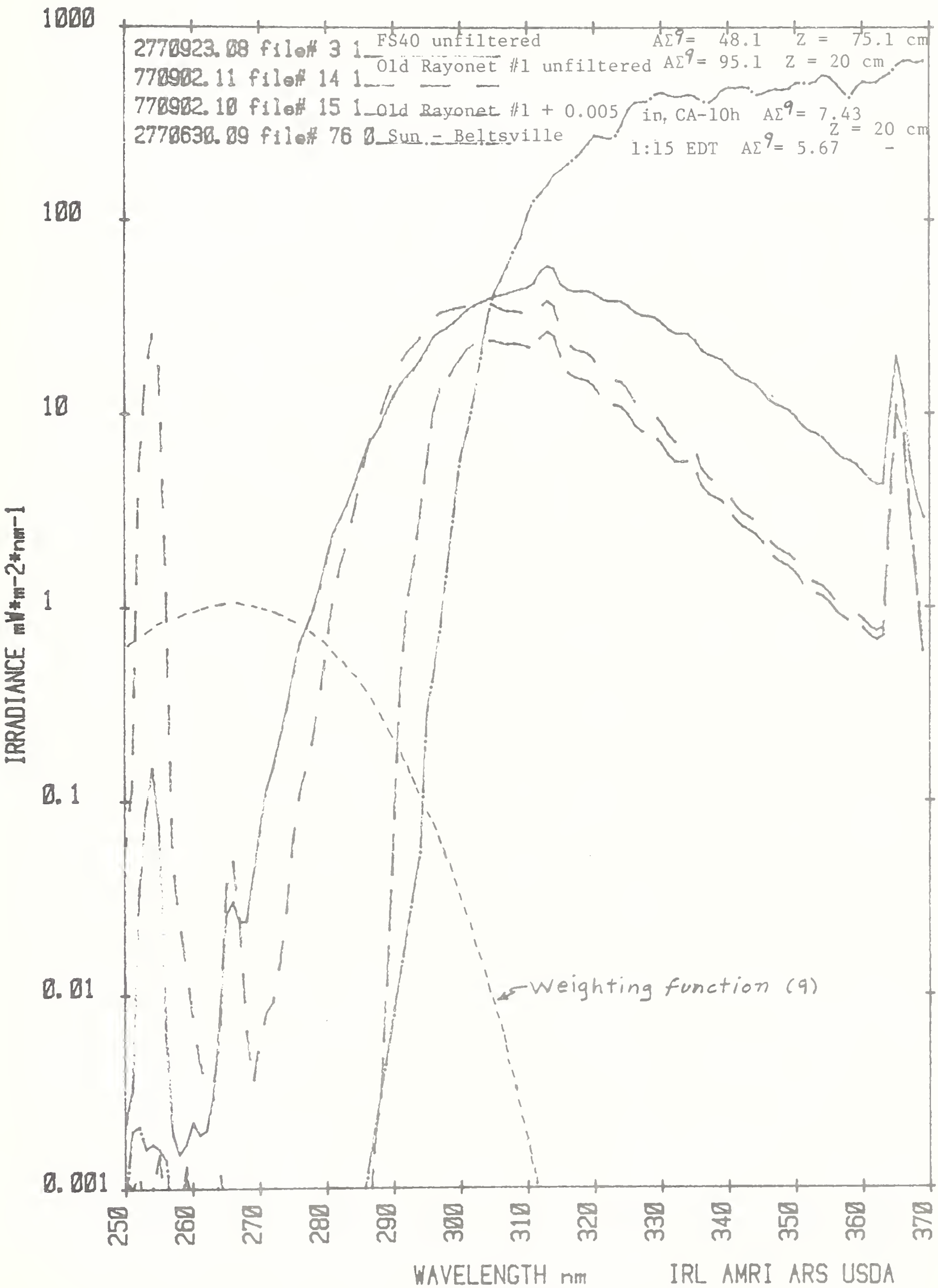

Fig. 30. Spectra FS40 and Rayonet F8T5 RPR 3000A°

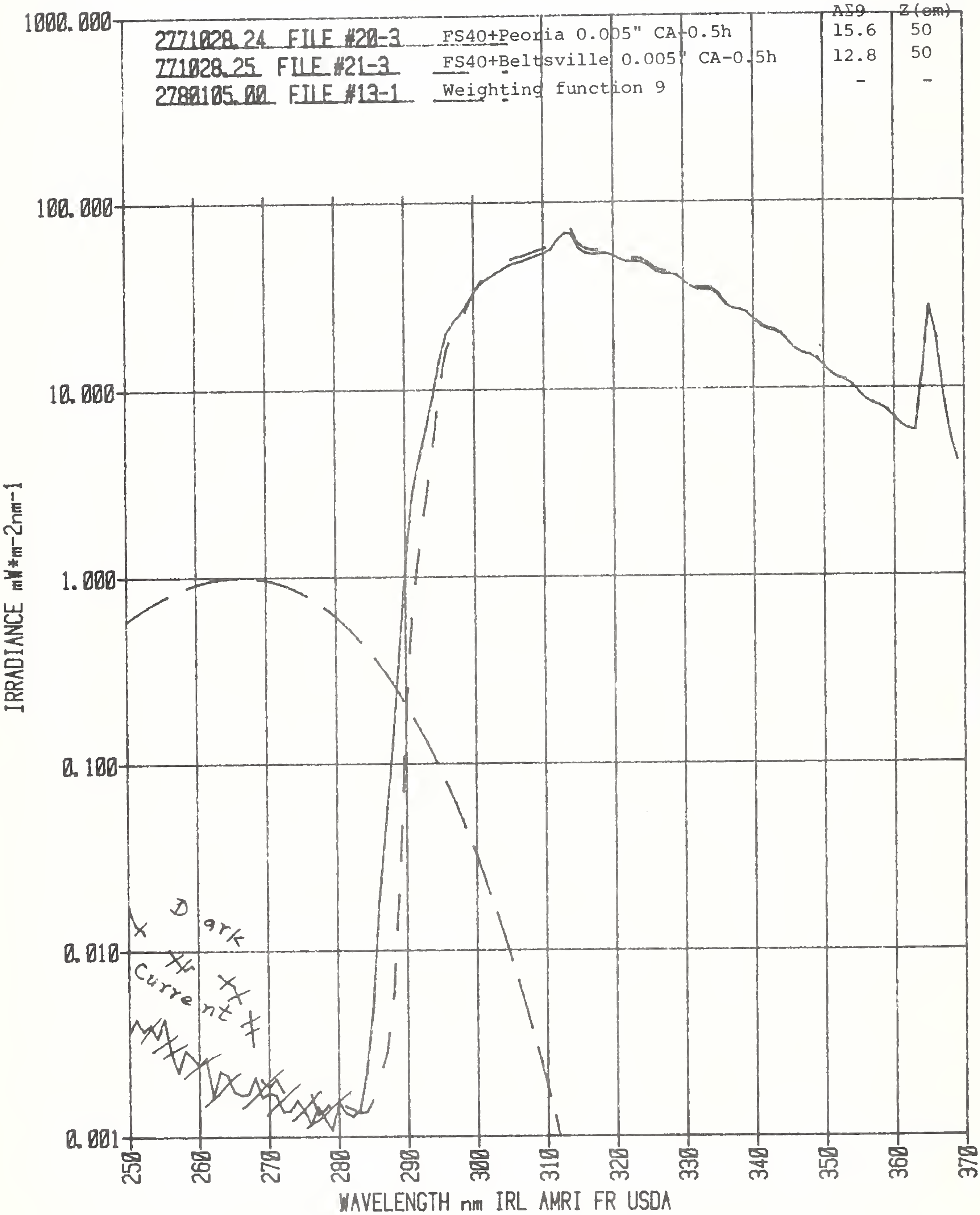

Fig. 31. Spectra FS40 and cellulose acetate aged 0.5 hr. Z = 50 cm

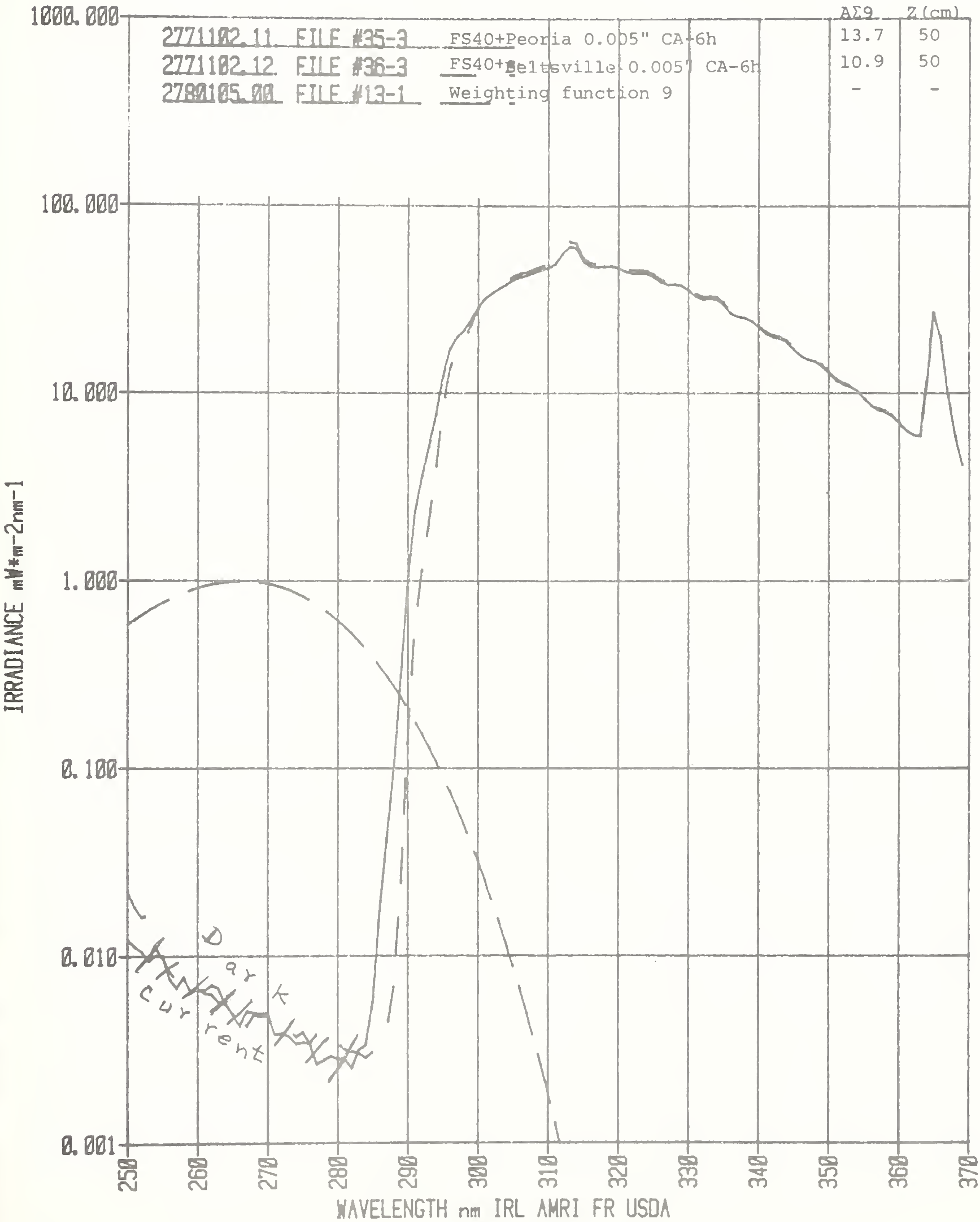

Fig. 32. Spectra FS40 and cellulose acetate aged 6 hr Z = 50 cm

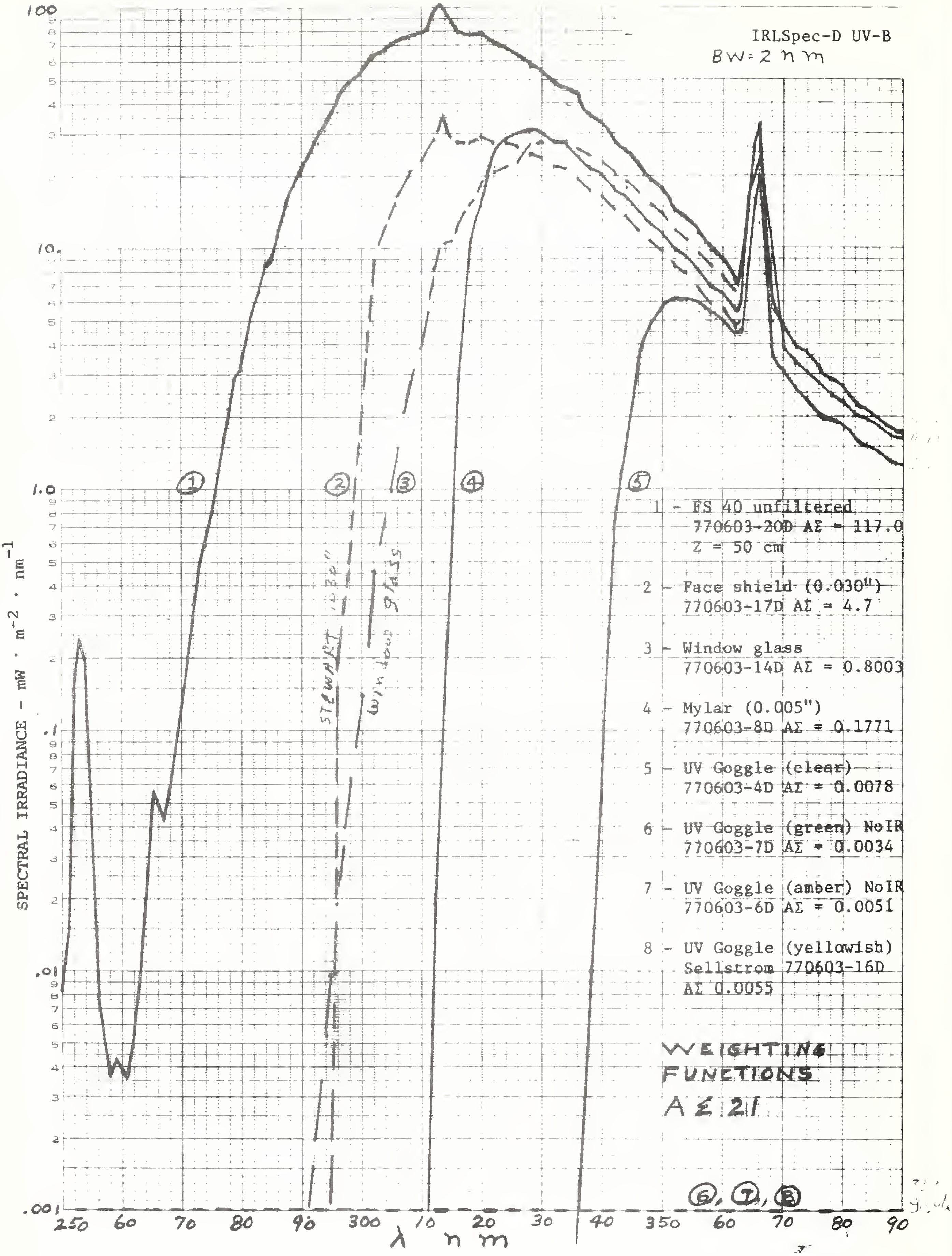

Fig. 33. Spectra - eye protective device

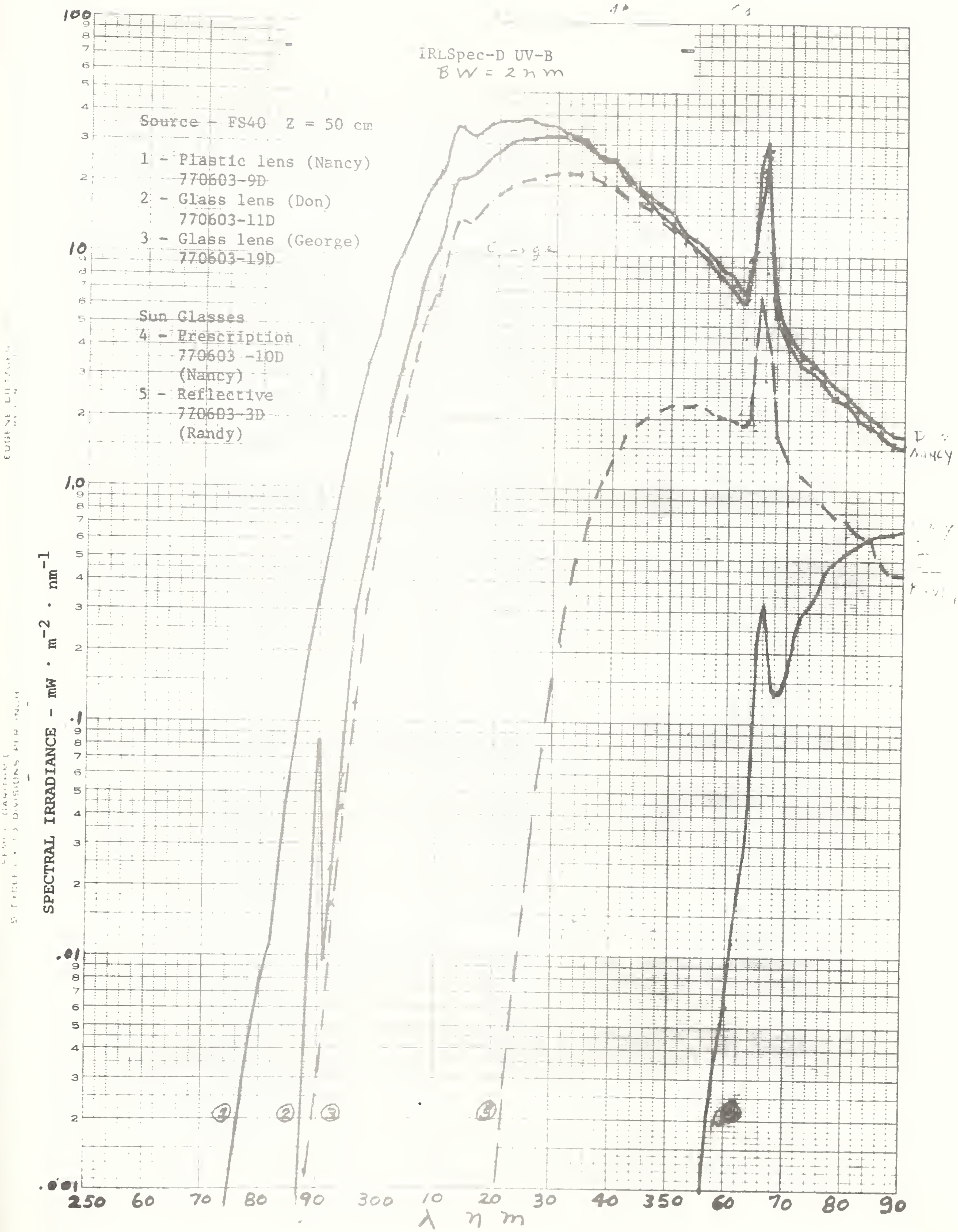

Fig. 34. Spectra prescription eyeglasses and sunglasses

APPENDIX A

```
AUTO START
A-IRR. CAL. SCAN
B-REV
C-CAL. WLGTH
D-SCAN SPECTRA
E-STOP
F-FORWARD
G-PRT. DATA
I-ACT. INT. 9
K-WLGTH. CHECK
L-STD. LAMP EQ
M-SUMS
N-CONT. READ
ENTER YR.MO.DAY#
  2780120.00
RESET

FILE      0
TYPE      0
USED      746
MAX       1000


0000 PRNTø
0002 A
0003 -
0004 I
0005 R
0006 R
0007 .
0008
0009 C
0010 A
0011 L
0012 .
0013
0014 S
0015 C
0016 A
0017 N
0018 B
0019 -
0020 R
0021 E
0022 V
0023
0024 LINE
0025 C
0026 -
0027 C
0028 A
0029 L
0030 .
0031
0032 W
0033 L
0034 G
0035 T
0036 H
0037 LINE
0038 D
0039 -
0040 S
0041 C
0042 A
0043 N
0044
0045 S
0046 P
0047 E
0048 C
0049 T
0050 R
0051 A
0052 LINE
0053 E
0054 -
0055 S
0056 T
0057 O
0058 P
0059 LINE
0060 F
0061 -
0062 F
0063 O
0064 R
0065 W
0066 A
0067 R
0068 D
0069 LINE
0070 G
0071 -
0072 P
0073 R
0074 T
0075 .
0076
0077 D
0078 A
0079 T
0080 A
0081 LINE
0082 I
0083 -
0084 A
0085 C
0086 T
0087 .
0088
0089 I
0090 N
0091 T
0092 .
0093
0094 9
0095 LINE
0096 K
0097 -
0098 W
0099 L
0100 G
0101 T
0102 H
0103 .
0104
0105 C
0106 H
0107 E
0108 C
0109 K
0110 LINE
0111 L
0112 -
0113 S
0114 T
0115 D
0116 .
0117
0118 L
0119 A
0120 M
0121 P
0122
0123 E
0124 Q
```

Fig. Ala. Operate Program IRLSpec-D (Cassette D4)

```
0125 LINE
0126 M
0127 -
0128 S
0129 U
0130 M
0131 S
0132 LINE
0133 N
0134 -
0135 C
0136 O
0137 N
0138 T
0139 .
0140
0141 R
0142 E
0143 A
0144 D
0145 LINE
0146 E
0147 N
0148 T
0149 E
0150 R
0151
0152 Y
0153 R
0154 .
0155 M
0156 O
0157 .
0158 D
0159 A
0160 Y
0161 #
0162 END∝
0163 STOP
0164 FIX      2
0166 2
0167 EEX
0168 6
0169 +
0170 STO      R000
0172 PRINT
0173 5
0174 MASK     4
0176 1
0177 5
0178 1
```

```
0179 #REGS
0180 GOTO     0695
0182 CLEAR
0183 6
0184 +≑-
0185 ENTER↑
0186 1
0187 FRMT     4
0189 STOP
0190 LBL
---- C
0192 LBL
---- C
0194 PRNT∝
0196 W
0197 .
0198 L
0199 .
0200
0201 C
0202 A
0203 L
0204 .
0205 END∝
0206 5
0207 0
0208 STO      F
0209 SFG      2
0210 LBL
---- D
0212 LBL
---- D
0214 FIX      2
0216 .
0217 0
0218 1
0219 STO+     R000
0221 RCL      R000
0223 PRINT
0224 FIX      4
0226 1
0227 STO      A
0228 IF SFG 2
0229 GOTO     0235
0231 1
0232 2
0233 0
0234 STO      F
0235 3
0236 9
0237 STO      G
```

```
0238 1
0239 ENTER↑
0240 0
0241 +≑-
0242 LOAD
0243 5
0244 WBYTE    4
0246 READ     4
0248 ENTER↑
0249 4
0250 +≑-
0251 IF X=Y
0252 GOTO     0256
0254 GOTO     0
0256 3
0257 WBYTE    4
0259 FOR      A→F
0260 1
0261 STO      B
0262 READ     4
0264 IF 0
0265 GOTO     0269
0267 GOTO     0
0269 X≑Y
0270 IF SFG 4
0271 GOTO     0530
0273 STO      C
0274 6
0275 WBYTE    4
0277 FOR      B→G
0278 READ     4
0280 X≑Y
0281 STO+     C
0282 NEXT     B
0283 3
0284 WBYTE    4
0286 RCL      C
0287 RCL I    A
0289 -
0290 10↑X
0291 STO I    A
0293 CFG      4
0294 RCL      A
0295 2
0296 4
0297 9
0298 +
0299 ENTER↑
0300 1
0301 EEX
0302 3
```

Fig. A1b. Operate Program IRLSpec-D (Cassette D4) (cont'd)

```
0303 +
0304 +
0305 PRINT
0306 IF CFG 9
0307 GOTO    0316
0309 .
0310 0
0311 1
0312 STO-    R000
0314 GOTO    0317
0316 NEXT    A
0317 1
0318 WBYTE   4
0320 CFG     9
0321 RCL     A
0322 8
0323 0
0324 -
0325 IF +
0326 GOTO    1
0328 IF SFG 2
0329 GOTO    K
0331 RETURN
0332 LBL
---- F
0334 3
0335 WBYTE   4
0337 RETURN
0338 LBL
---- E
0340 CLEAR
0341 WBYTE   4
0343 RETURN
0344 LBL
---- B
0346 1
0347 WBYTE   4
0349 1
0350 RETURN
0351 LBL
---- I
0353 PRNT∅
0355 I
0356 N
0357 T
0358 .
0359 9
0360
0361 F
0362 R
0363 O
0364 M
0365 END∅
0366 2
0367 8
0368 0
0369 STOP
0370 FIX     0
0372 PRINT
0373 ENTER↑
0374 2
0375 4
0376 9
0377 -
0378 STO     A
0379 9
0380 0
0381 STO     F
0382 CLEAR
0383 STO     I
0384 FOR     A→F
0385 RCL     A
0386 2
0387 4
0388 9
0389 +
0390 2
0391 2
0392 8
0393 .
0394 1
0395 7
0396 8
0397 ÷
0398 9
0399 Y↑X
0400 STO     H
0401 4
0402 ÷
0403 4
0404 Y↑X
0405 STO     J
0406 RCL     H
0407 4
0408 -
0409 +≠-
0410 e↑X
0411 RCL     J
0412 +
0413 RCL I   A
0415 +
0416 ACC+
0417 NEXT    A
0418 RCL     I
0419 FIX     4
0421 PRINT
0422 ENTER↑
0423 3
0424 .
0425 0
0426 6
0427 ÷
0428 PRNT∅
0430 S
0431 U
0432 N
0433 S
0434
0435 =
0436 PRINT
0437 END∅
0438 GOTO    M
0440 LBL
---- A
0442 .
0443 0
0444 1
0445 STO+    R000
0447 FIX     2
0449 RCL     R000
0451 PRINT
0452 FIX     3
0454 1
0455 STO     A
0456 1
0457 5
0458 0
0459 STO     F
0460 4
0461 0
0462 STO     G
0463 1
0464 STO     E
0465 5
0466 WBYTE   4
0468 READ    4
0470 ENTER↑
0471 4
0472 +≠-
0473 IF X=Y
0474 GOTO    0478
0476 GOTO    0
0478 3
0479 WBYTE   4
0481 FOR     A→F
```

Fig. Alc. Operate Program IRLSpec-D (Cassette D4) (cont'd)

```
0482 READ    4
0484 IF 0
0485 GOTO    0489
0487 GOTO    0
0489 X≑Y
0490 IF SFG 4
0491 GOTO    0530
0493 CLEAR
0494 STO     C
0495 6
0496 WBYTE   4
0498 FOR     B→G
0499 READ    4
0501 X≑Y
0502 STO+    C
0503 NEXT    B
0504 3
0505 WBYTE   4
0507 1
0508 STO     B
0509 RCL     C
0510 STO+ 1  A
0512 +≑-
0513 RCL     A
0514 2
0515 4
0516 9
0517 +
0518 ENTER↑
0519 EEX
0520 4
0521 ÷
0522 +
0523 PRINT
0524 IF SFG 8
0525 GOTO    0541
0527 NEXT    A
0528 GOTO    0541
0530 PRNTα
0532 O
0533 V
0534 E
0535 R
0536 L
0537 O
0538 A
0539 D
0540 ENDα
0541 1
0542 WBYTE   4
0544 CFG     8
0545 CFG     4
0546 RETURN
0547 LBL
---- L
0549 LBL
---- L
0551 CLEAR
0552 1
0553 LD&GO
0554 LBL
---- K
0556 RCL     R047
0558 RCL     R048
0560 ÷
0561 LOG
0562 ENTER↑
0563 4
0564 ÷
0565 +≑-
0566 2
0567 9
0568 6
0569 .
0570 5
0571 +
0572 FIX     2
0574 PRNTα
0576 LINE
0577 L
0578 I
0579 N
0580 E
0581
0582 A
0583 T
0584 PRINT
0585 ENDα
0586 FIX     4
0588 CFG     2
0589 STOP
0590 LBL
---- M
0592 PRNTα
0594 S
0595 U
0596 M
0597
0598 F
0599 R
0600 O
0601 M
0602
0603 ENDα
0604 STOP
0605 FIX     0
0607 PRINT
0608 2
0609 4
0610 9
0611 -
0612 STO     A
0613 PRNTα
0615 T
0616 O
0617
0618 ENDα
0619 STOP
0620 PRINT
0621 2
0622 4
0623 9
0624 -
0625 STO     F
0626 CLEAR
0627 STO     I
0628 FOR     A→F
0629 RCL     A
0630 2
0631 4
0632 9
0633 -
0634 RCL I   A
0636 STO+    I
0637 NEXT    A
0638 FIX     4
0640 RCL     I
0641 PRNTα
0643 M
0644 I
0645 L
0646 L
0647 I
0648 W
0649 A
0650 T
0651 T
0652 S
0653 /
0654 M
0655 S
0656 Q
0657 PRINT
0658 ENDα
```

Fig. Ald. Operate Program IRLSpec-D (Cassette D4) (cont'd)

```
0659 GOTO    M
0661 LBL
---- N
0663 CLEAR
0664 STO     C
0665 4
0666 WBYTE   4
0668 4
0669 0
0670 STO     G
0671 1
0672 STO     B
0673 FOR     B→G
0674 READ    4
0676 X⇌Y
0677 STO+    C
0678 NEXT    B
0679 RCL     C
0680 PAUSE
0681 PAUSE
0682 CLEAR
0683 STO     C
0684 GOTO    0671
0686 LBL
---- O
0688 LBL
---- O
0690 .
0691 0
0692 1
0693 STO-    R000
0695 CLEAR
0696 WBYTE   4
0698 1
0699 WBYTE   4
0701 PRNT⌀
0703 R
0704 E
0705 S
0706 E
0707 T
0708 END⌀
0709 GOTO    0182
0711 LBL
---- G
0713 LBL
---- G
0715 RCL     R000
0717 FIX     2
0719 PRINT
0720 1
0721 STO     A
0722 1
0723 2
0724 0
0725 STO     F
0726 FIX     4
0728 FOR     A→F
0729 RCL I   A
0731 RCL     A
0732 2
0733 4
0734 9
0735 +
0736 ENTER↑
0737 1
0738 EEX
0739 3 .
0740 ÷
0741 +
0742 PRINT
0743 NEXT    A
0744 STOP
0745 END
```

Fig. Ale. Operate Program IRLSpec-D (Cassette D4) (cont'd)

```
FILE      1
TYPE      0
USED    218
MAX     800

0000 PRNT∝
0002 C
0003 A
0004 L
0005 I
0006 B
0007 R
0008 A
0009 T
0010 I
0011 O
0012 N
0013 LINE
0014 C
0015 O
0016 R
0017 R
0018 E
0019 C
0020 T
0021 I
0022 O
0023 N
0024
0025 W
0026 I
0027 L
0028 L
0029 LINE
0030 B
0031 E
0032
0033 P
0034 E
0035 C
0036 O
0037 R
0038 D
0039 E
0040 D
0041
0042 O
0043 N
0044 LINE
0045
0046
0047 F
0048 I
0049 L
0050 E
0051
0052
0053
0054 0
0055
0056 A
0057 N
0058 D
0059
0060 -
0061 1
0062 LINE
0063 LINE
0064 LINE
0065
0066
0067 N
0068 O
0069 .
0070
0071 R
0072 U
0073 N
0074 S
0075 =
0076 ?
0077 END∝
0078 STOP
0079 STO      E
0080 1
0081 STO      A
0082 1
0083 5
0084 0
0085 STO      F
0086 .
0087 0
0088 0
0089 3
0090 5
0091 +÷-
0092 STO      I
0093 1
0094 .
0095 3
0096 1
0097 7
0098 STO      J
0099 2
0100 .
0101 3
0102 7
0103 6
0104 STO      B
0105 2
0106 1
0107 4
0108 STO      D
0109 .
0110 2
0111 1
0112 4
0113 6
0114 STO      H
0115 FOR      A÷F
0116 RCL      A
0117 2
0118 4
0119 9
0120 +
0121 RCL      I
0122 ×
0123 RCL      J
0124 +
0125 10↑X
0126 +÷-
0127 RCL      B
0128 +
0129 10↑X
0130 STO      C
0131 RCL      A
0132 2
0133 4
0134 9
0135 +
0136 RCL      D
0137 -
0138 .
0139 5
0140 ÷
0141 1/X
0142 STO-     C
0143 RCL      A
0144 3
0145 1
0146 -
0147 RCL      H
0148 ×
0149 ENTER↑
0150 ×
0151 +÷-
0152 e↑X
0153 .
0154 1
0155 +÷-
0156 ×
0157 STO+     C
0158 RCL I    A
0160 RCL      E
0161 ÷
0162 RCL      C
0163 LOG
0164 -
0165 STO I    A
0167 PRINT
0168 NEXT     A
0169 1
0170 5
0171 0
0172 ENTER↑
0173 1
0174 ENTER↑
0175 0
0176 +÷-
0177 RCDATA
0178 1
0179 5
0180 0
0181 ENTER↑
0182 1
0183 ENTER↑
0184 1
0185 +÷-
0186 RCDATA
0187 PRNT∝
0189 C
0190 A
0191 L
0192 .
0193
0194 C
0195 O
0196 N
0197 S
0198 T
0199 .
0200
0201 I
0202 N
0203 LINE
0204 1
0205
0206 T
0207 O
0208
0209 1
0210 5
0211 0
0212 END∝
0213 CLEAR
0214 STO
0215 CLEAR
0216 LD&GO
0217 END
```

Fig. A2. Calibrate Program IRLSpec-D (Cassette D2)

DATE 780210
E UV SPECTRA
1780210.01

OPERATE PROGRAM IRLSpec-S

0000 CHA	0051 CHA	0101 IO1	0151 RM	0201 04
0001 D	0052 U	0102 FLG	0152 11	0202 SP
0002 A	0053 V	0103 00	0153 −	0203 8b
0003 T	0054	0104 IFER	0154 R	0204 71
0004 E	0055 S	0105 01	0155 IND	0205 R
0005 CHA	0056 P	0106 IO6	0156 RM	0206 RM
0006 E	0057 E	0107 IO1	0157 00	0207 41
0007 +	0058 C	0108 ÷	0158 =	0208 −
0008 1	0059 T	0109 RM	0159 10ˣ	0209 L
0009 EXP	0060 R	0110 11	0160 R	0210 RM
0010 6	0061 A	0111 −	0161 IND	0211 42
0011 =	0062	0112 L	0162 SM	0212 =
0012 SM	0063 CHA	0113 IND	0163 01	0213 LOG
0013 10	0064 FIX5	0114 RM	0164 IO2	0214 ×
0014 E	0065 02	0115 00	0165 FIX5	0215 1
0015 SP	0066 COL	0116 =	0166 03	0216 =
0016 8a	0067 10	0117 10ˣ	0167 COL	0217 SC
0017 3	0068 CHA	0118 L	0168 08	0218 +
0018 7	0069	0119 IND	0169 →	0219 70
0019 0	0070 W	0120 SM	0170 01	0220 RM
0020 SM	0071 L	0121 01	0171 1	0221 13
0021 06	0072	0122 SM	0172 ΣM	0222 =
0022 FLG	0073	0123 03	0173 00	0223 71
0023 10	0074	0124 IO2	0174 ΣM	0224 FIX5
0024 8	0075 I	0125 RM	0175 01	0225 02
0025 0	0076 R	0126 02	0176 ΣM	0226 COL
0026 SM	0077 R	0127 FIX5	0177 02	0227 07
0027 00	0078 A	0128 00	0178 RM	0228 L
0028 1	0079 D	0129 COL	0179 02	0229 RM
0029 4	0080 .	0130 03	0180 −	0230 63
0030 0	0081	0131 RM	0181 RM	0231 −
0031 SM	0082	0132 03	0182 06	0232 R
0032 01	0083 W	0133 FIX5	0183 =	0233 RM
0033 2	0084 L	0134 03	0184 IF−	0234 63
0034 5	0085	0135 COL	0185 00	0235 =
0035 0	0086	0136 08	0186 FLG	0236 LOG
0036 SM	0087	0137 →	0187 01	0237 ×
0037 02	0088 I	0138 01	0188 IO6	0238 2
0038 f9	0089 R	0139 1	0189 CHA	0239 =
0039 IO6	0090 R	0140 ΣM	0190 0	0240 SC
0040 CHA	0091 A	0141 02	0191 CHA	0241 +
0041 2	0092 D	0142 RM	0192 IO2	0242 70
0042 CHA	0093 .	0143 02	0193 LF	0243 RM
0043 IO2	0094 CHA	0144 FIX5	0194 RM	0244 14
0044 .	0095 →	0145 00	0195 02	0245 =
0045 0	0096 01	0146 COL	0196 −	0246 FIX5
0046 1	0097 IO6	0147 03	0197 RM	0247 02
0047 ΣM	0098 CHA	0148 IO6	0198 07	0248 COL
0048 10	0099 7	0149 IO1	0199 =	0249 07
0049 RM	0100 CHA	0150 ÷	0200 IF+	0250 LF
0050 10				

Fig. A3a

OPERATE PROGRAM IRLSpec-S (cont'd)

```
0251 E
0252 FLG
0253 04
0254 SP
0255 8c
0256 CM
0257 02
0258 CHA
0259 S
0260 T
0261 A
0262 R
0263 T
0264
0265 I
0266 N
0267 T
0268 .
0269 9
0270
0271 A
0272 T
0273 ?
0274 CHA
0275 E
0276 IFE
0277 12
0278 2
0279 8
0280 0
0281 ◊
0282 FLG
0283 12
0284 -
0285 1
0286 7
0287 0
0288 =
0289 ÷
0290 2
0291 =
0292 SM
0293 01
0294 +
0295 1
0296 0
0297 0
0298 =
0299 SM
0300 00
0301 FLG
0302 02
0303 L
0304 IND
0305 RM
0306 00
0307 ×
0308 L
0309 IND
0310 RM
0311 01
0312 =
0313 ΣM
0314 02
0315 R
0316 IND
0317 RM
0318 00
0319 ×
0320 R
0321 IND
0322 RM
0323 01
0324 =
0325 ΣM
0326 02
0327 1
0328 ΣM
0329 00
0330 ΣM
0331 01
0332 RM
0333 01
0334 -
0335 7
0336 9
0337 =
0338 IF-
0339 02
0340 RM
0341 02
0342 FIX5
0343 03
0344 COL
0345 08
0346 CHA
0347
0348 S
0349 U
0350 N
0351 S
0352 CHA
0353 ÷
0354 RM
0355 15
0356 =
0357 FIX5
0358 05
0359 COL
0360 16
0361 LF
0362 SP
0363 8d
0364 FLG
0365 07
0366 CHA
0367 S
0368 U
0369 M
0370
0371 F
0372 R
0373 O
0374 M
0375 CHA
0376 E
0377 SM
0378 03
0379 CHA
0380 T
0381 O
0382 CHA
0383 E
0384 SM
0385 04
0386 CM
0387 02
0388 RM
0389 03
0390 ÷
0391 2
0392 +
0393 1
0394 5
0395 =
0396 SM
0397 03
0398 FLG
0399 03
0400 L
0401 IND
0402 RM
0403 03
0404 ΣM
0405 02
0406 R
0407 IND
0408 RM
0409 03
0410 ΣM
0411 02
0412 1
0413 ΣM
0414 03
0415 RM
0416 03
0417 -
0418 1
0419 5
0420 =
0421 ×
0422 2
0423 -
0424 RM
0425 04
0426 =
0427 IF-
0428 03
0429 LF
0430 RM
0431 02
0432 FIX5
0433 03
0434 ◊
0435 GT
0436 07
0437 SP
0438 8e
0439 3
0440 0
0441 0
0442 SM
0443 06
0444 GT
0445 10
0446 CHA
0447 M
0448 E
0449 M
0450 .
0451
0452 F
0453 R
0454 O
0455 M
0456 CHA
0457 LF
0458 E
0459 SM
0460 08
0461 CHA
0462 T
0463 O
0464 CHA
0465 E
0466 LF
0467 SM
0468 09
0469 FLG
0470 11
0471 L
0472 IND
0473 RM
0474 08
0475 FIX5
0476 03
0477 COL
0478 12
0479 R
0480 IND
0481 RM
0482 08
0483 FIX5
0484 03
0485 COL
0486 10
0487 LF
0488 1
0489 ΣM
0490 08
0491 RM
0492 08
0493 -
0494 RM
0495 09
0496 =
0497 IF-
0498 11
0499 EP
0500 00
```

Fig. A3b

```
AUTO START
A SPECTRA
B REVERSE
C S L CAL.
E STOP
F FORWARD
G PRINT DATA
I INTEGRAL
J RUN WLGTH
K WLGTH EQUAT.
L STD LAMP EQUA
M SUM
O OPERATE
ENTER YR.MO.DAY#

  3780120.00
READY
HIT A C OR J

FILE      0
TYPE      0
USED      720
MAX       800

0000 PRNTα
0002 A
0003
0004 S
0005 P
0006 E
0007 C
0008 T
0009 R
0010 A
0011 LINE
0012 B
0013
0014 R
0015 E
0016 V
0017 E
0018 R
0019 S
0020 E
0021
0022 LINE
0023 C
0024
0025 S
0026
0027 L
0028
0029 C
0030 A
0031 L
0032 .
0033 LINE
0034 E
0035
0036 S
0037 T
0038 O
0039 P
0040 LINE
0041 F
0042
0043 F
0044 O
0045 R
0046 W
0047 A
0048 R
0049 D
0050 LINE
0051 G
0052
0053 P
0054 R
0055 I
0056 N
0057 T
0058
0059 D
0060 A
0061 T
0062 A
0063 LINE
0064 I
0065
0066 I
0067 N
0068 T
0069 E
0070 G
0071 R
0072 A
0073 L
0074 LINE
0075 J
0076
0077 R
0078 U
0079 N
0080
0081 W
0082 L
0083 G
0084 T
0085 H
0086 LINE
0087 K
0088
0089 W
0090 L
0091 G
0092 T
0093 H
0094
0095 E
0096 Q
0097 U
0098 A
0099 T
0100 .
0101 LINE
0102 L
0103
0104 S
0105 T
0106 D
0107
0108 L
0109 A
0110 M
0111 P
0112
0113 E
0114 Q
0115 U
0116 A
0117 LINE
0118 M
0119
0120 S
0121 U
0122 M
0123 LINE
0124 O
0125
0126 O
0127 P
0128 E
0129 R
0130 A
0131 T
0132 E
0133
0134 LINE
0135 E
0136 N
0137 T
0138 E
0139 R
0140
0141 Y
0142 R
0143 .
0144 M
0145 O
0146 .
0147 D
0148 A
0149 Y
0150 #
0151 LINE
0152 ENDα
0153 STOP
0154 3
0155 EEX
0156 6
0157 +
0158 FIX        2
0160 PRINT
0161 STO        F000
0163 2
0164 5
0165 4
0166 0
0167 STO        B
0168 2
0169 5
0170 1
0171 0
0172 STO        D
0173 FIX        4
```

Fig. A4a. Operate Program IRLSpec-SO (Cassette B)

```
0175 1
0176 5
0177 1
0178 #REGS
0179 LBL
---- O
0181 LBL
---- O
0183 CFG       8
0184 CFG       3
0185 PRNT∝
0187 R
0188 E
0189 A
0190 D
0191 Y
0192 LINE
0193 H
0194 I
0195 T
0196
0197 A
0198
0199 C
0200
0201 O
0202 R
0203
0204 J
0205 LINE
0206 END∝
0207 STOP
0208 LBL
---- A
0210 LBL
---- A
0212 1
0213 ENTER↑
0214 HNDSK     4
0216 2
0217 WBYTE     4
0219 1
0220 ENTER↑
0221 0
0222 +⇌-
0223 LOAD
0224 FIX       2
0226 .
0227 0
0228 1
```

```
0229 STO+     R000
0231 RCL      R000
0233 PRINT
0234 FIX      4
0236 3
0237 WBYTE    4
0239 1
0240 STO      A
0241 IF SFG   4
0242 GOTO     0248
0244 1
0245 2
0246 0
0247 STO      F
0248 FOR      A÷F
0249 START    4
0251 READ     4
0253 1
0254 EEX
0255 3
0256 ÷
0257 STO- I   A
0259 RCL I    A
0261 +⇌-
0262 10↑X
0263 STO I    A
0265 RCL      E
0266 -
0267 IF -
0268 CLEAR
0269 RCL      A
0270 2
0271 4
0272 9
0273 +
0274 ENTER↑
0275 1
0276 EEX
0277 3
0278 *
0279 +
0280 PRINT
0281 IF SFG   8
0282 GOTO     B
0284 NEXT     A
0285 IF SFG   4
0286 GOTO     K
0288 GOSUB    B
```

```
0290 LBL
---- I
0292 LBL
---- I
0294 PRNT∝
0296 I
0297 N
0298 T
0299 .
0300
0301 F
0302 R
0303 O
0304 M
0305
0306 ?
0307 END∝
0308 2
0309 8
0310 0
0311 STOP
0312 FIX      0
0314 PRINT
0315 FIX      4
0317 ENTER↑
0318 2
0319 4
0320 9
0321 -
0322 STO      A
0323 8
0324 0
0325 STO      F
0326 CLEAR
0327 STO      I
0328 FOR      A→F
0329 RCL      A
0330 2
0331 4
0332 9
0333 +
0334 2
0335 2
0336 8
0337 .
0338 1
0339 7
0340 8
0341 ÷
```

```
0342 9
0343 Y↑X
0344 STO
0345 4
0346 ÷
0347 4
0348 Y↑X
0349 STO
0350 RCL
0351 4
0352 -
0353 +⇌-
0354 e↑X
0355 RCL
0356 *
0357 RCL I
0359 +
0360 ACC+
0361 NEXT
0362 RCL
0363 PRNT∝
0365 LINE
0366 I
0367 N
0368 T
0369 E
0370 G
0371 R
0372 A
0373 L
0374
0375 9
0376
0377 =
0378 PRINT
0379 LINE
0380 LINE
0381 END∝
0382 ENTER↑
0383 3
0384 .
0385 0
0386 6
0387 ÷
0388 PRNT∝
0390 S
0391 U
0392 N
0393 S
```

Fig. A4b. Operate Program IRLSpec-SO (Cassette B) (cont'd)

```
0394
0395 =
0396
0397 PRINT
0398 LINE
0399 LINE
0400 END
0401 GOTO      M
0403 LBL
---- K
0405 LBL
---- K
0407 RCL      R004
0409 RCL      R005
0411 ÷
0412 LOG
0413 +⇌-
0414 ENTER↑
0415 3
0416 .
0417 4
0418 +
0419 2
0420 5
0421 3
0422 .
0423 5
0424 +
0425 FIX      2
0427 PRINT
0428 RCL      R047
0430 RCL      R048
0432 ÷
0433 LOG
0434 +⇌-
0435 ENTER↑
0436 3
0437 .
0438 5
0439 +
0440 2
0441 9
0442 6
0443 .
0444 5
0445 +
0446 PRINT
0447 FIX      4
0449 CFG      4
0450 GOSUB    B
0452 GOTO     0
0454 LBL
---- J
0456 LBL
---- J
0458 5
0459 0
0460 STO      F
0461 SFG      4
0462 GOTO     A
0464 LBL
---- F
0466 2
0467 WBYTE    4
0469 3
0470 WBYTE    4
0472 RETURN
0473 LBL
---- E
0475 2
0476 WBYTE    4
0478 CLEAR
0479 WBYTE    4
0481 RETURN
0482 LBL
---- C
0484 LBL
---- C
0486 .
0487 0
0488 1
0489 STO+     R000
0491 RCL      R000
0493 FIX      2
0495 PRINT
0496 1
0497 STO      A
0498 1
0499 5
0500 0
0501 STO      F
0502 SFG      3
0503 1
0504 ENTER↑
0505 HNDSK    4
0507 3
0508 WBYTE    4
0510 PAUSE
0511 PAUSE
0512 PAUSE
0513 FOR      A→F
0514 READ     4
0516 1
0517 EEX
0518 3
0519 -
0520 STO+ I   A
0522 +⇌-
0523 RCL      A
0524 2
0525 4
0526 9
0527 +
0528 ENTER↑
0529 1
0530 EEX
0531 3
0532 ÷
0533 +
0534 FIX      4
0536 PRINT
0537 IF SFG   6
0538 GOTO     E
0540 NEXT     A
0541 LBL
---- B
0543 LBL
---- B
0545 1
0546 ENTER↑
0547 HNDSK    4
0549 2
0550 WBYTE    4
0552 PAUSE
0553 0
0554 WBYTE    4
0556 PAUSE
0557 1
0558 WBYTE    4
0560 PAUSE
0561 5
0562 WBYTE    4
0564 READ     4
0566 READ     4
0568 RCL      E
0569 +
0570 IF -
```

Fig. A4c. Operate Program IRLSpec-SO (Cassette B) (cont'd)

```
0571 GOTO     0566
0573 1
[illegible]
0576 READ     4
0578 RCL      D
0579 +
0580 IF -
0581 GOTO     0576
0583 0
0584 WBYTE    4
0586 IF SFG 3
0587 STOP
0588 IF SFG 8
0589 GOTO     0712
0591 RETURN
0592 LBL
---- M
0594 LBL
---- M
0596 PRNT⍺
0598 R
0599 E
0600 C
0601 O
0602 R
0603 D
0604 ?
0605
0606 O
0607 R
0608 LINE
0609 S
0610 U
0611 M
0612
0613 F
0614 R
0615 O
0616 M
0617 END⍺
0618 CLEAR
0619 STOP
0620 IF 0
0621 GOTO     0
0623 FIX      0
0625 PRINT
0626 2
0627 [illegible]
0628
0629 -
0630 STO      A
0631 PRNT⍺
0633 T
0634 O
0635 END⍺
0636 STOP
0637 PRINT
0638 2
0639 4
0640 9
0641 -
0642 STO      F
0643 CLEAR
0644 STO      I
0645 FOR      A→F
0646 RCL I    A
0648 STO+     I
0649 NEXT     A
0650 FIX      4
0652 RCL      I
0653 PRNT⍺
0655 M
0656 I
0657 L
0658 L
0659 I
0660 W
0661 A
0662 T
0663 T
0664 S
0665 /
0666 M
0667 S
0668 Q
0669
0670 PRINT
0671 LINE
0672 LINE
0673 END⍺
0674 GOTO     M
0676 LBL
---- [illegible]
0678 LBL
---- G
0680 1
0681 STO      A
0682 1
0683 5
0684 0
0685 STO      F
0686 FIX      4
0688 FOR      A→F
0689 RCL I    A
0691 RCL      A
0692 2
0693 4
0694 9
0695 +
0696 ENTER↑
0697 1
0698 EEX
0699 [illegible]
0700 [illegible]
0701 +
0702 PRINT
0703 NEXT     A
0704 STOP
0705 LBL
---- L
0707 LBL
---- L
0709 CLEAR
0710 1
0711 LD&GO
0712 .
0713 0
0714 1
0715 STO-     R000
0717 GOTO     0
0719 END
```

Fig. A4d. Operate Program IRLSpec-SO (Cassette B) (cont'd)

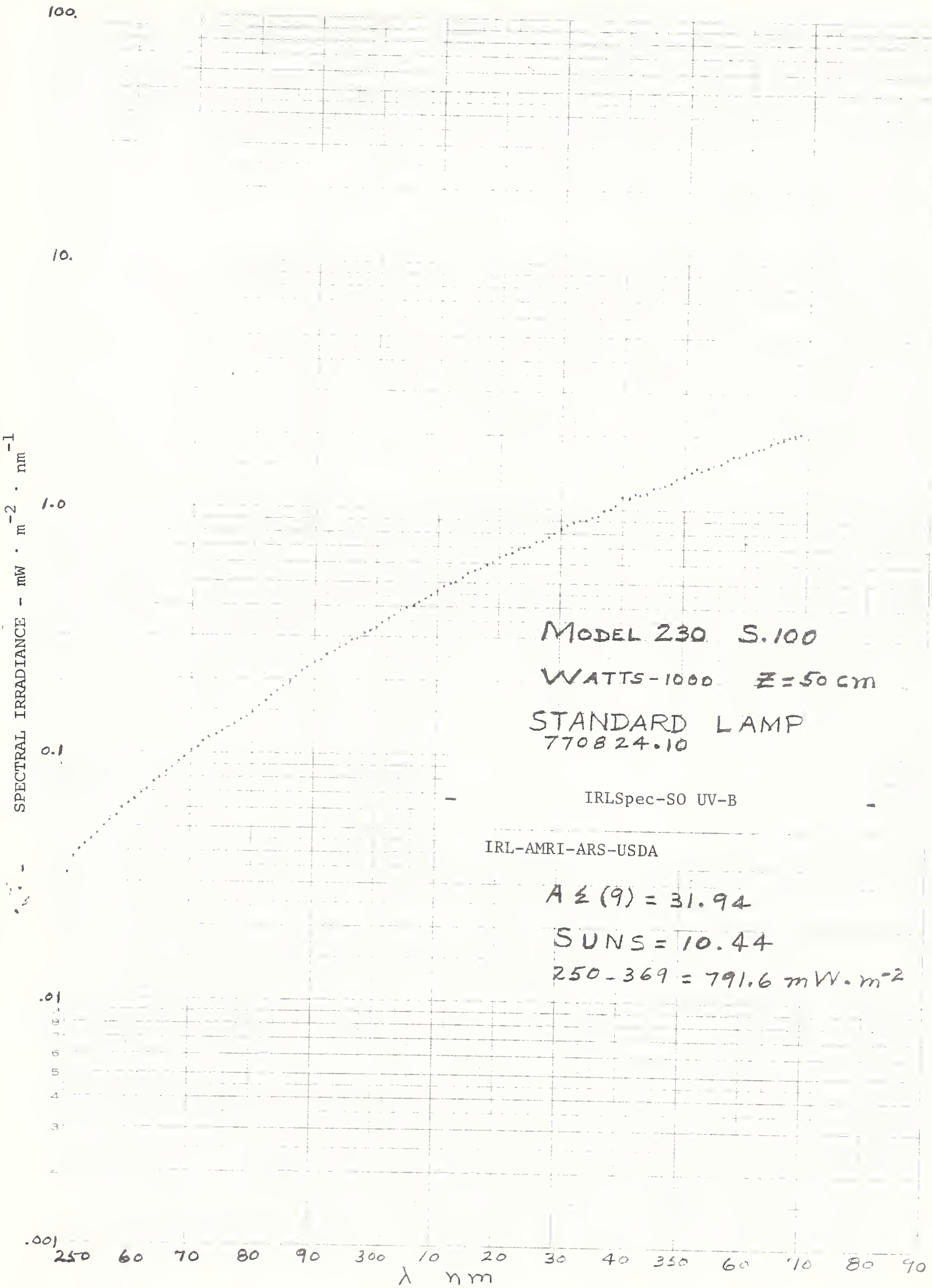

Fig. A5 - Standard Lamp Plotted Each nm

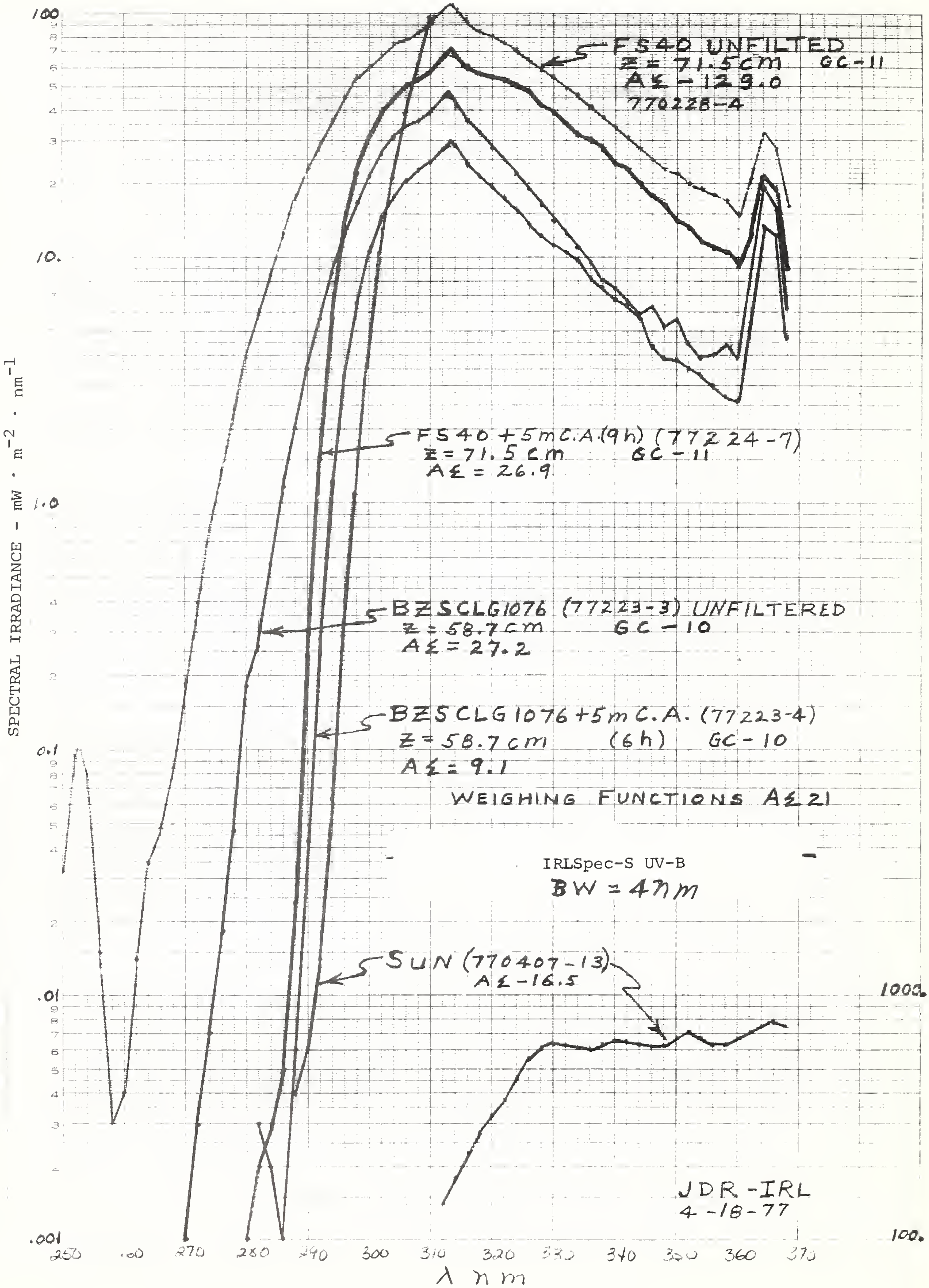

Fig. A6 - FS40, FBZS40CLG1076, Sun, IRLSpec-S

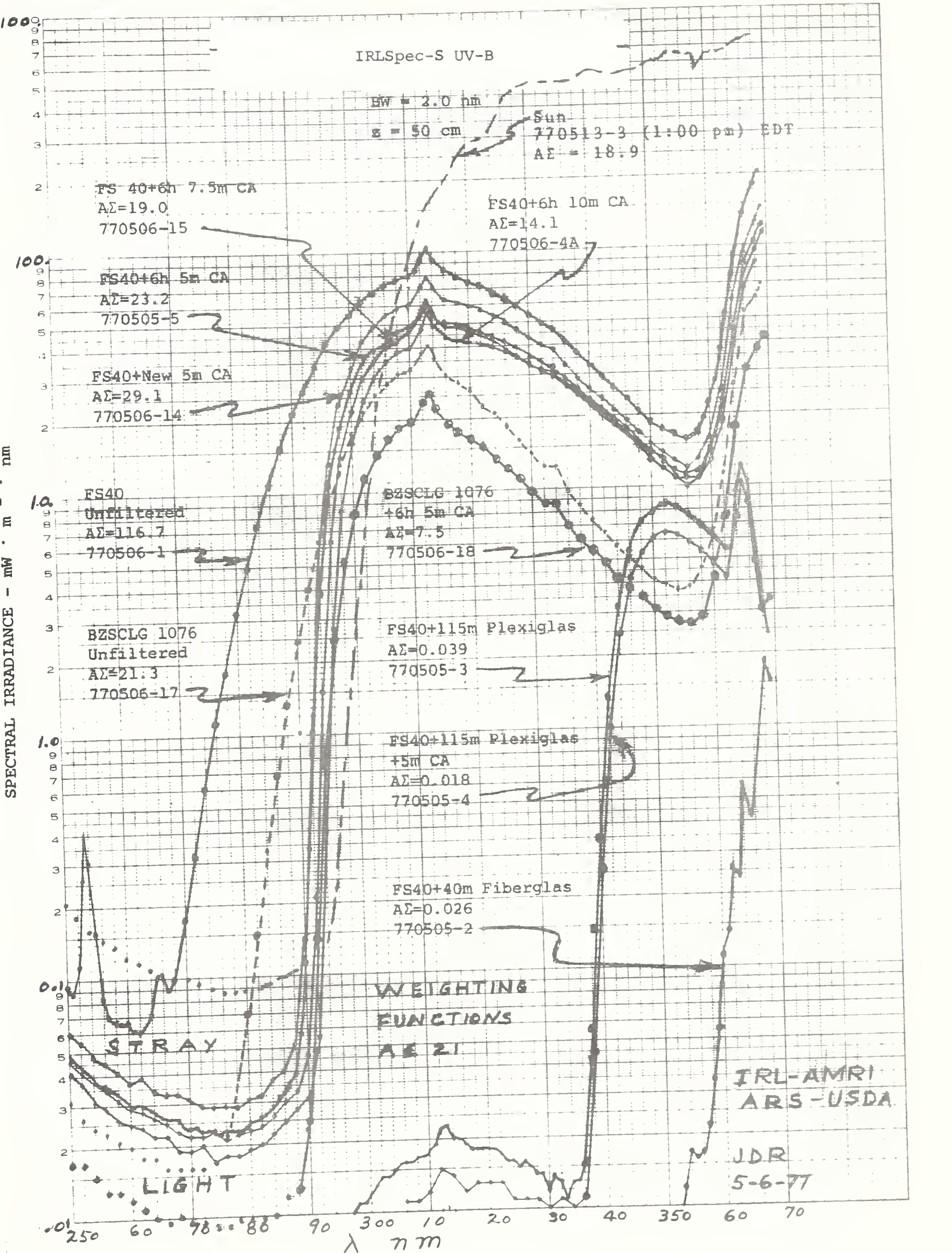

Fig. A7 - Filtered FS40 and FBZS40CLG1076, IRLSpec-S

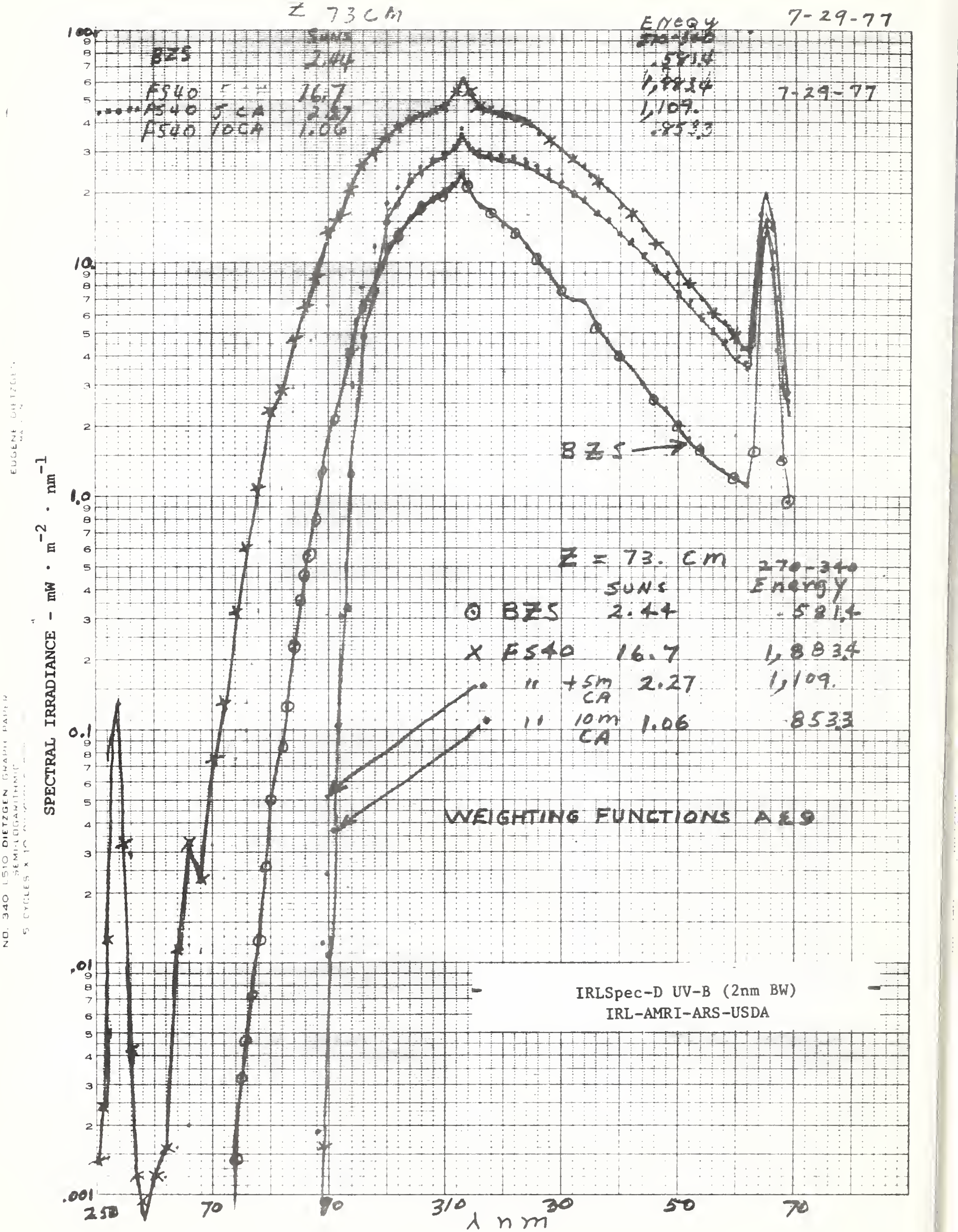

Fig. A8 - FS40, FBZS40CLG1076, Z = 73 cm, IRLSpec-D

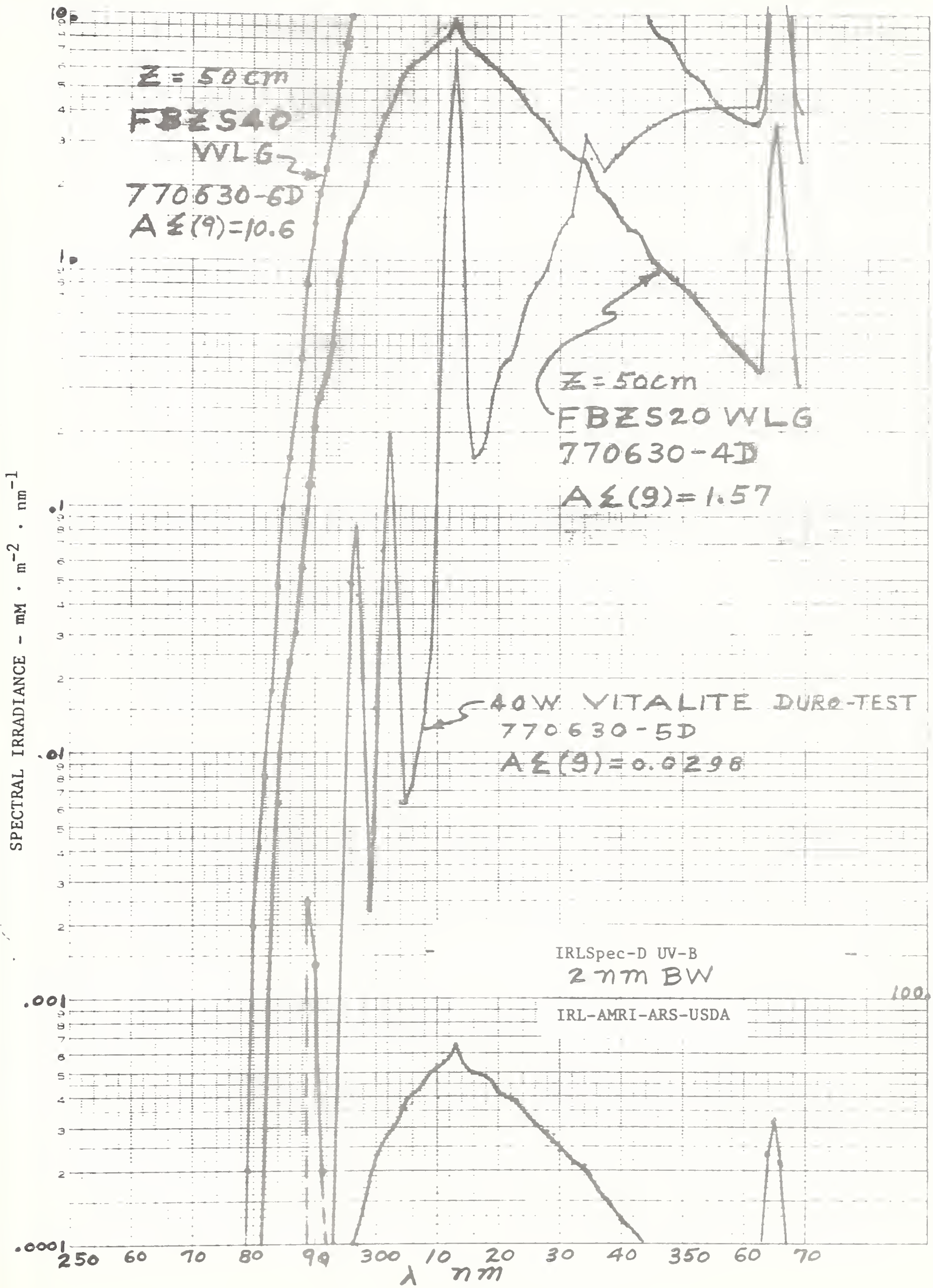

Fig. A9 - FBZS40 WLG, FBZS20 WLG, Vitalite, IRLSpec-D

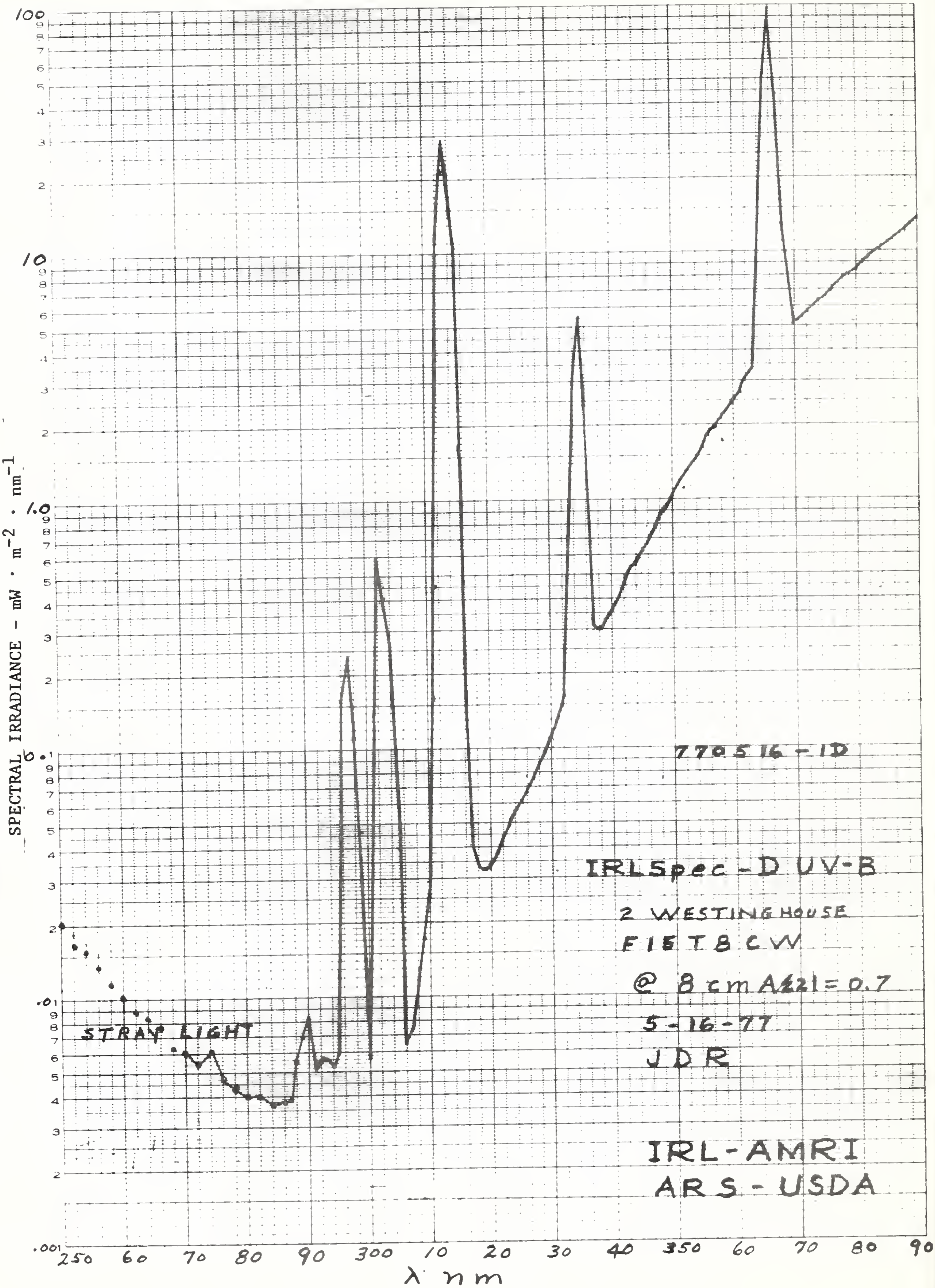

Fig. A10 - F15T8 CW Westinghouse, IRLSpec-D

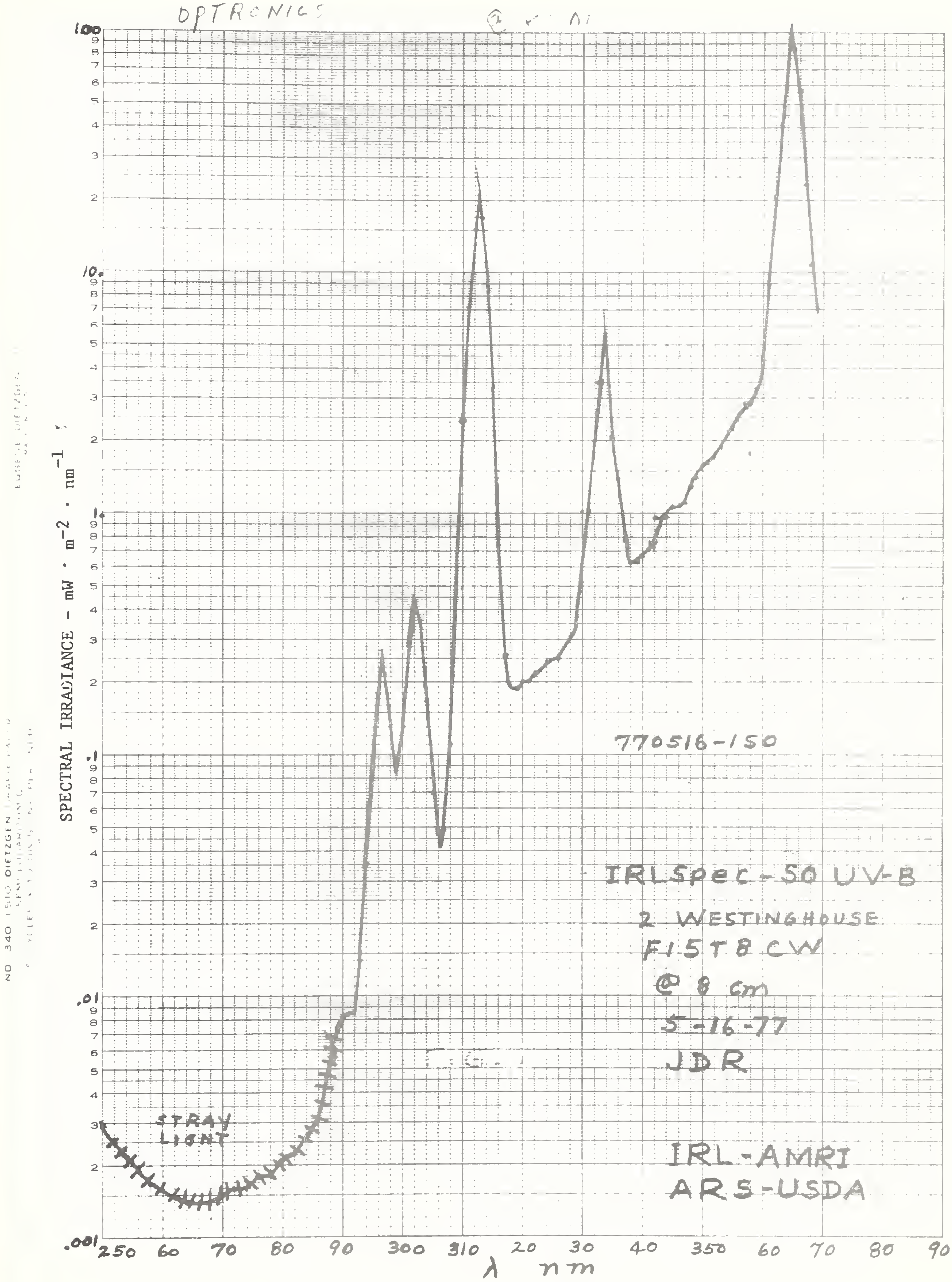

Fig. A11 - F15T8 CW Westinghouse, IRLSpec-50

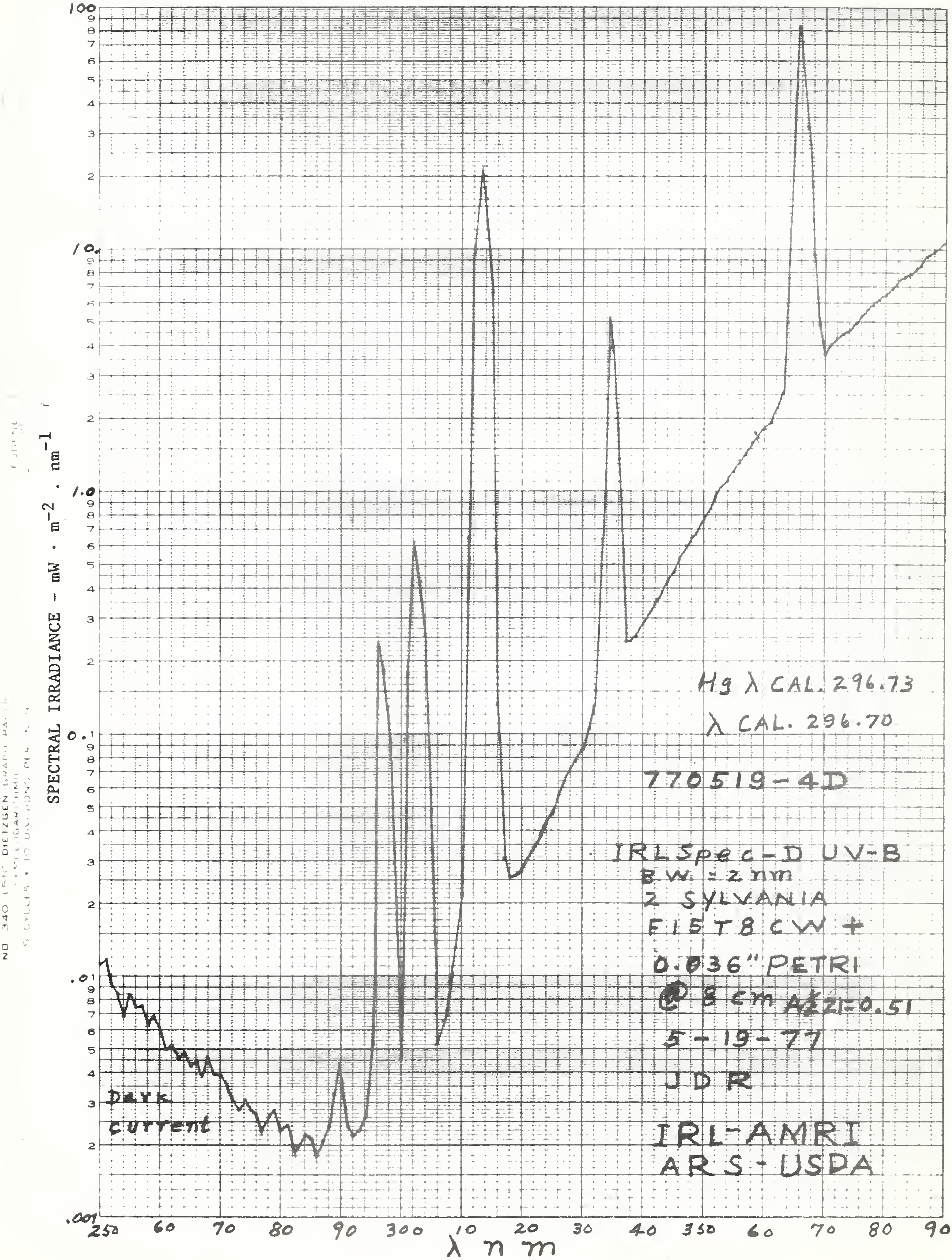

Fig. A12 - F15T8 CW Sylvania, IRLSpec-D

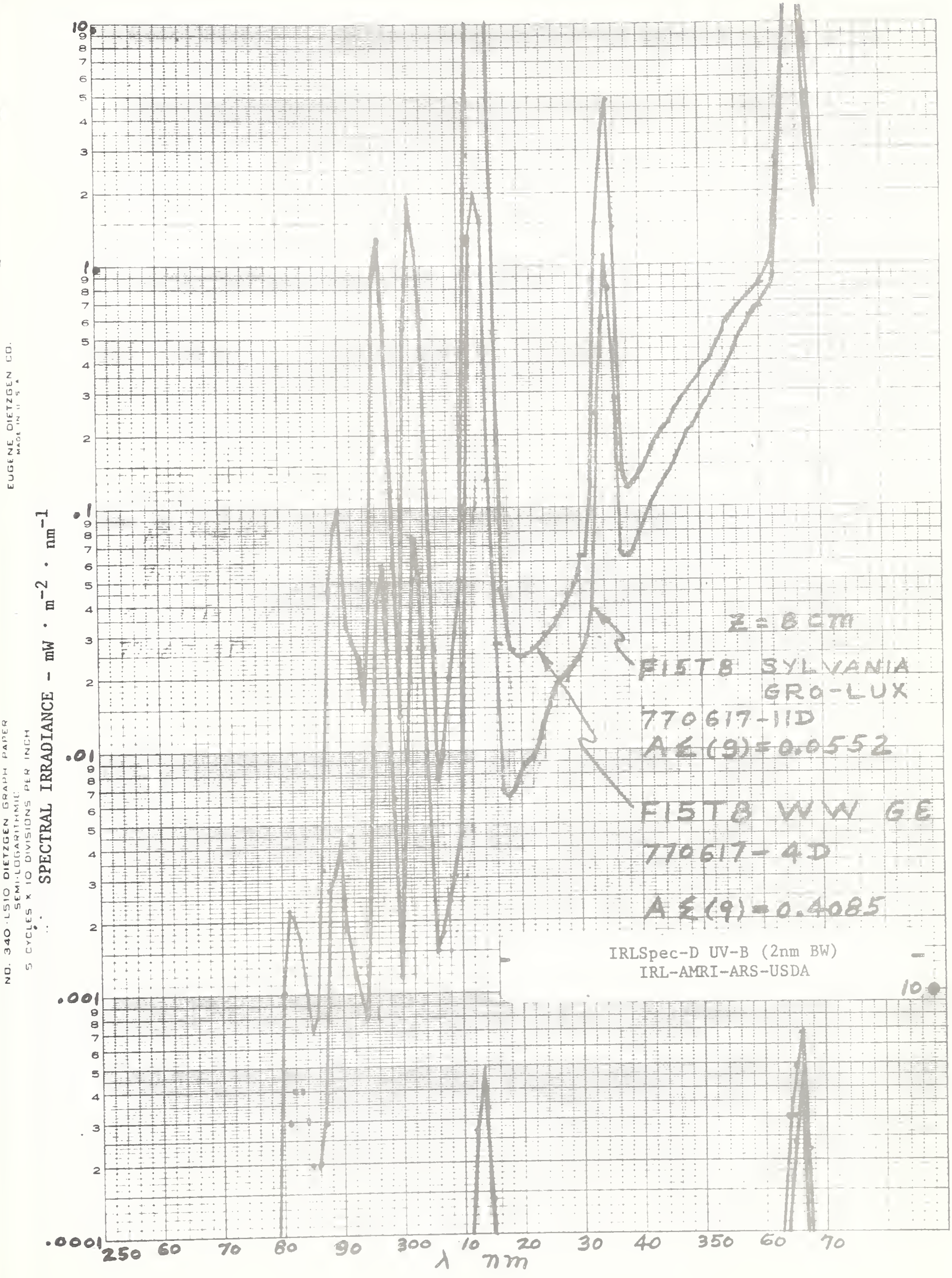

Fig. A13 - F15T8 GRO-LUX Sylvania F15T8 WW GE, IRLSpec-D

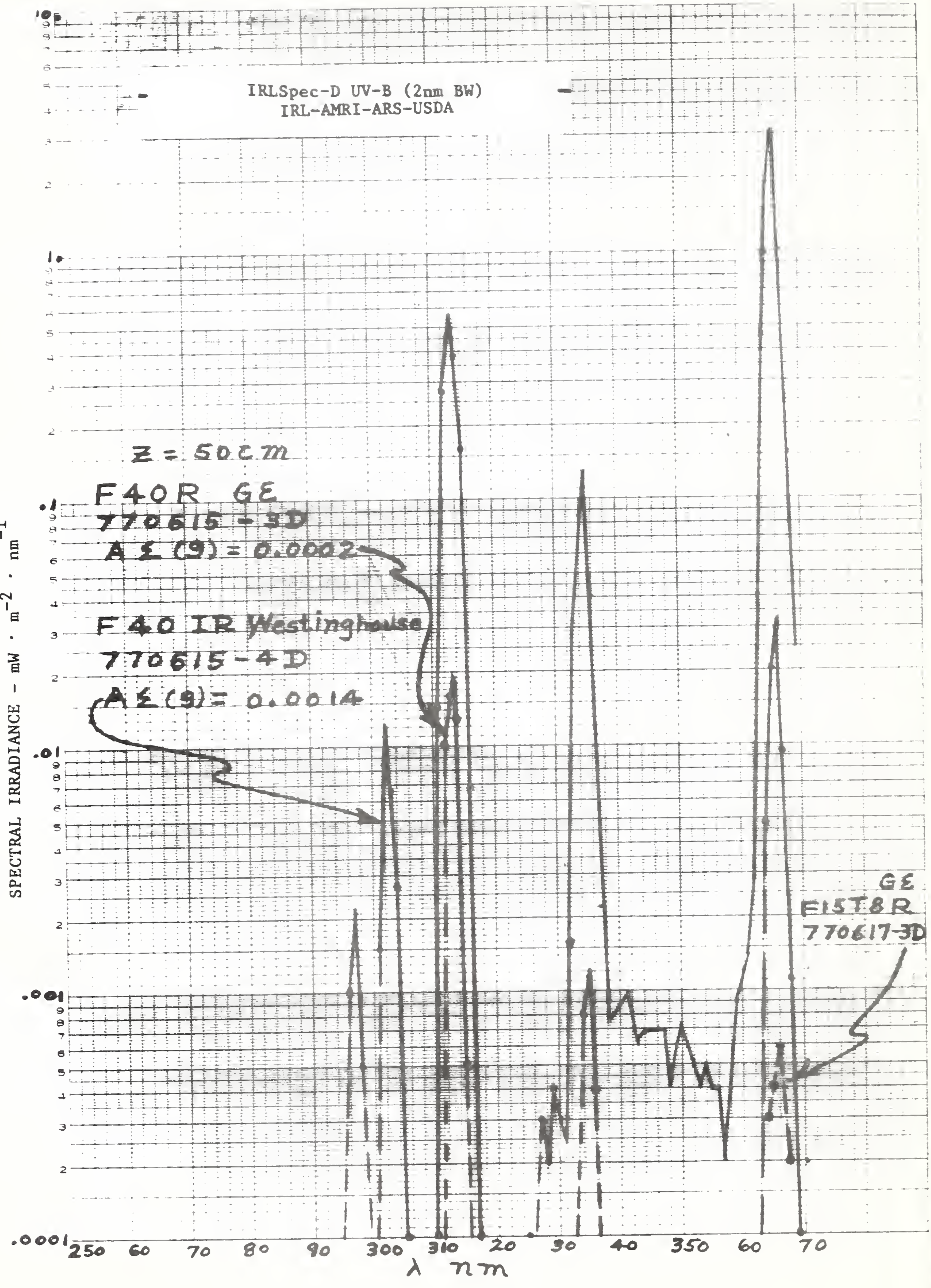

Fig. A14 - F40R GE, F40IR Westinghouse, F15T8R GE, Z - 50 cm, IRLSpec-D

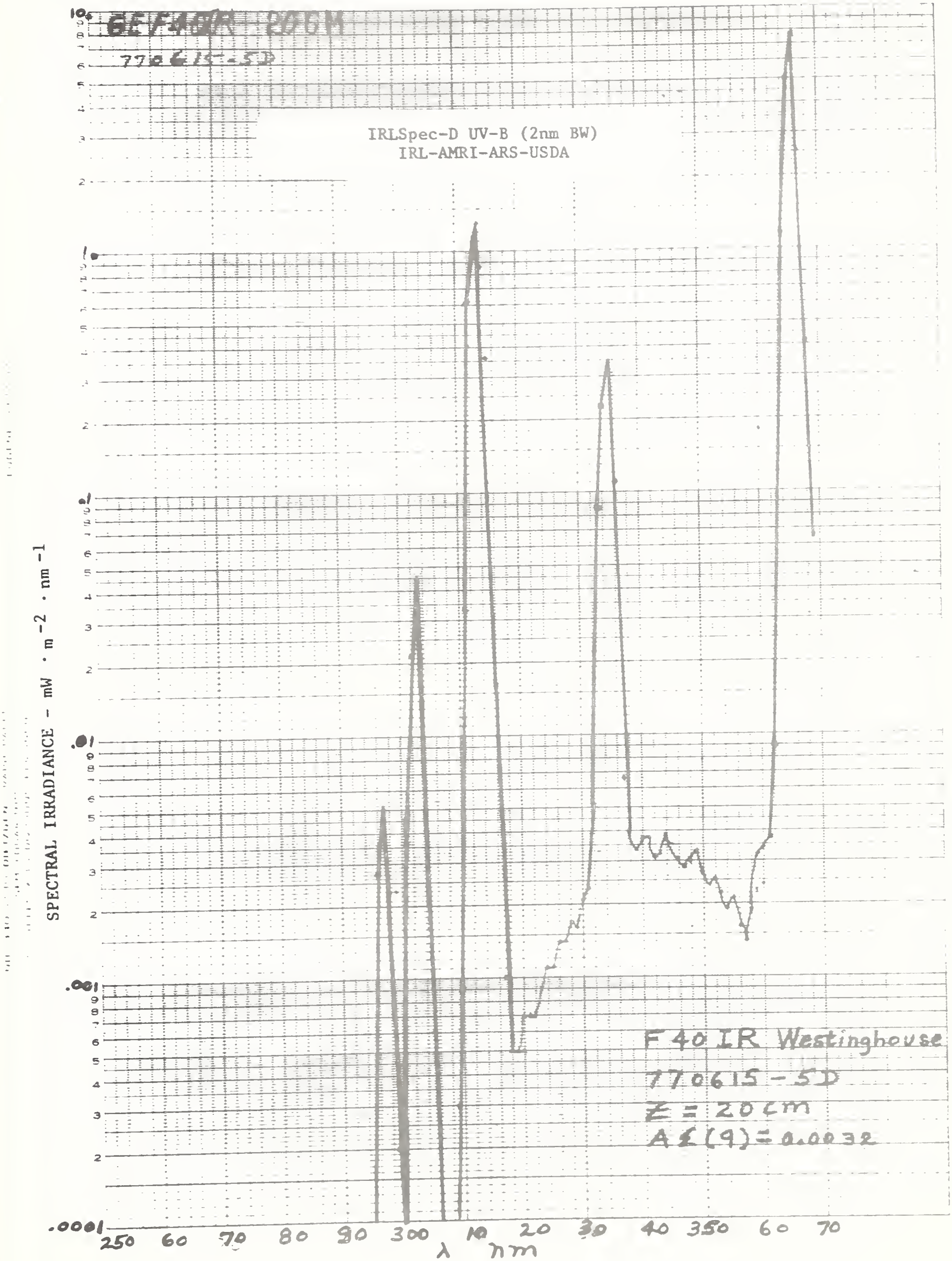

Fig. A15 - F40IR Westinghouse, Z = 20 cm, IRLSpec-D

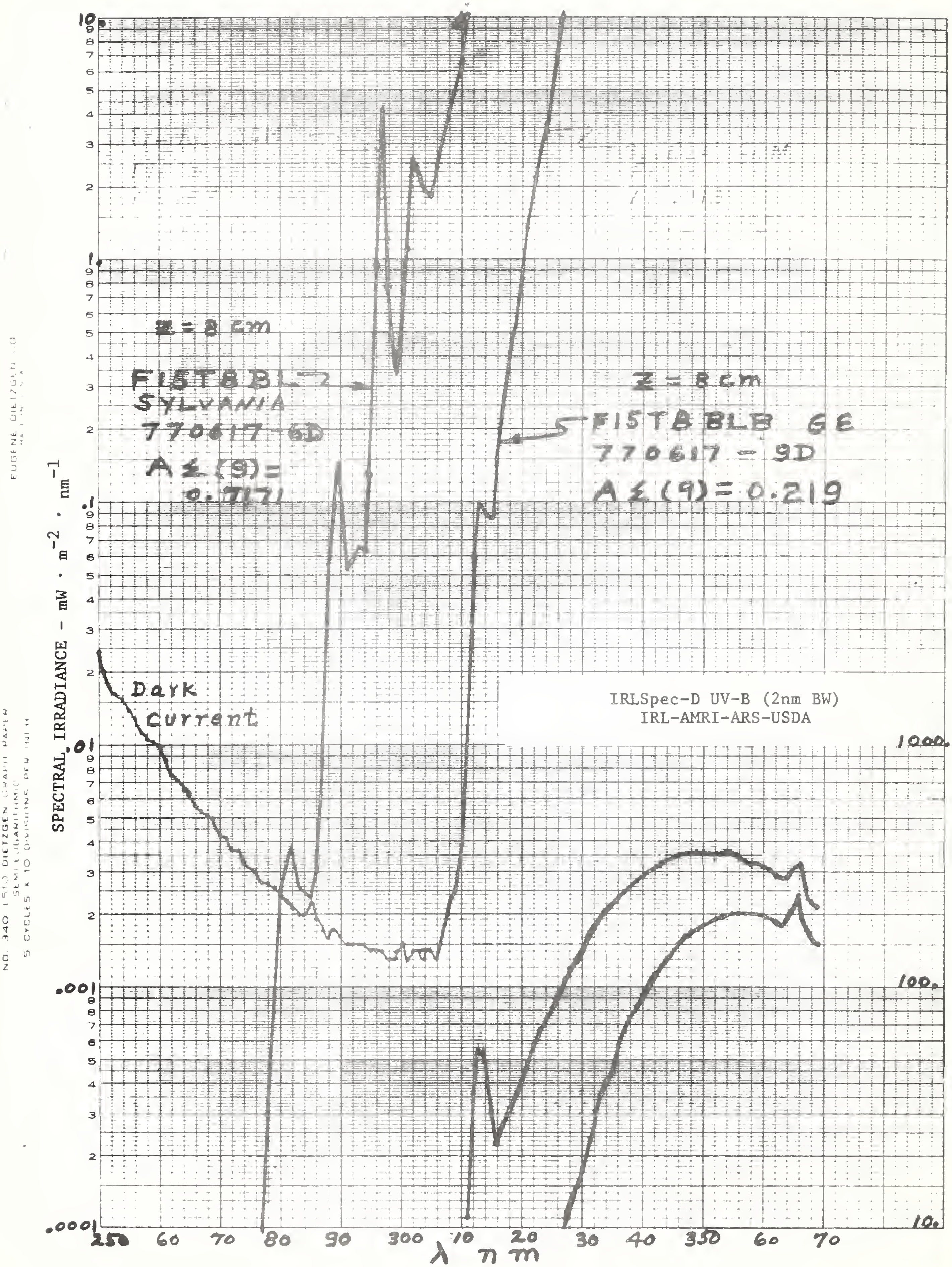

Fig. A16 - F15T8BL Sylvania, F15T8BLB GE, IRLSpec-D

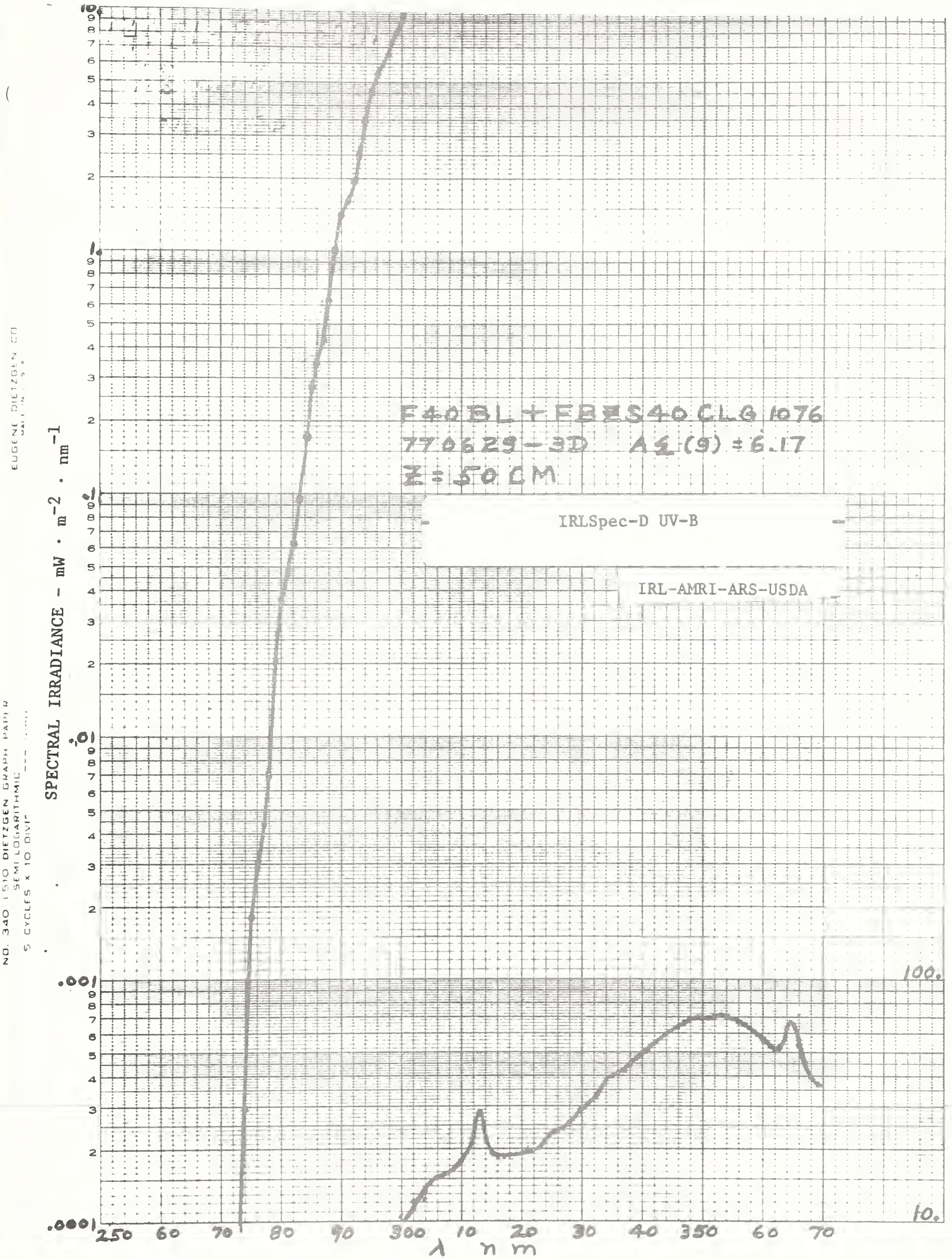

Fig. A17 - F40 BL + FBZS40 CLG1076, IRLSpec-D

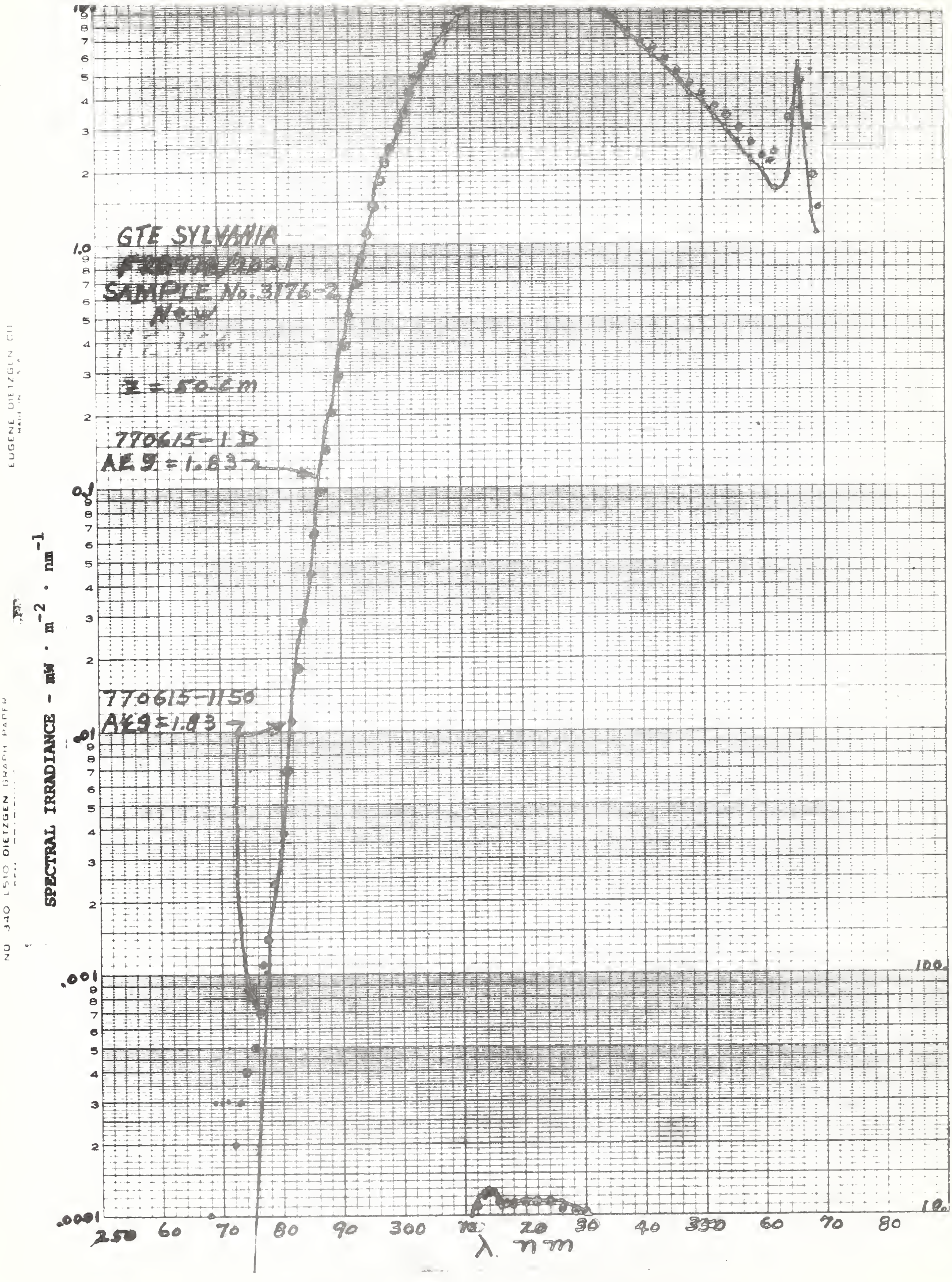

Fig. A18 - F20T12/2021 Sample No. 3176-2, IRLSpec-D, IRLSpec-SO

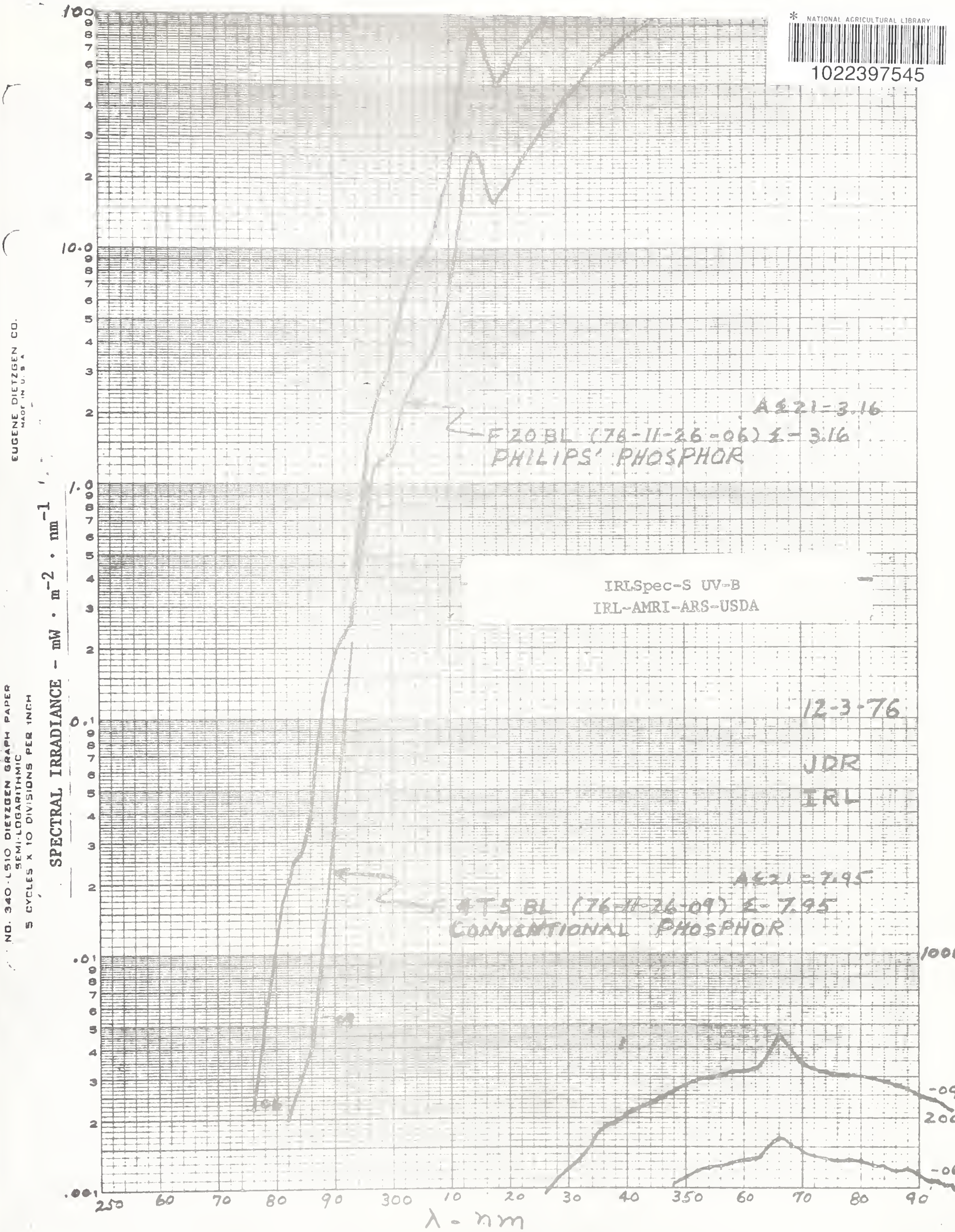

Fig. A19 - F20BL Phillips phosphor, F4T5BL conventional phospher, IRLSpec-S